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On the Parallax and Proper Motion of the Double Star Krueger 60 (*Burnham, Gen. Cat.*, 11761). By E. E. Barnard. (Plate 14.)

The History of Krueger 60.

Professor Krueger, in his catalogue of the Astronomische Gesellschaft, covering the zone $+55°$ to $+65°$, noted with the meridian instrument many stars which were double. He made a rough estimate of the quadrant and distances of these stars and of their magnitudes.

In 1890 Professor Burnham measured 67 stars from Krueger's list with the 12-inch and 36-inch telescopes of the Lick Observatory (*Pub. L.O.*, vol. ii.). The star No. 60 was among those measured. Krueger's note on this object is:—

"Dupl. 12″ pr. com. 9·3."

In measuring the principal star, Professor Burnham found that it was a wide and unequal double.

		°	″		m	m	
1890·788	Pos.	178·8	Dist. 2·32	(1 n)	9·0	– 12	A B
		56·3	26·82	(1 n)		9·2	A C

Of these A C is the Krueger pair.

No other measures were made of these stars until 1898, when Dr. Eric Doolittle remeasured them with the 18-inch Brashear telescope of the Flower Observatory (*A.J.*, vol. xxi. p. 47).

Doolittle's measures showed that the pair A B had a strong proper motion (0″·93 in the direction 247°·9). His measures are—

	°	″	m	m	
1898·446	140·66	3·19	9·1 –	10·5	A B } 5 n.
	58·71	34·39		9·4	A C }

Subsequent measures fully confirmed these results.

In *A.J.*, vol. xxi. p. 64, I have given measures of these stars which are in accord with the motion derived by Doolittle. (In the

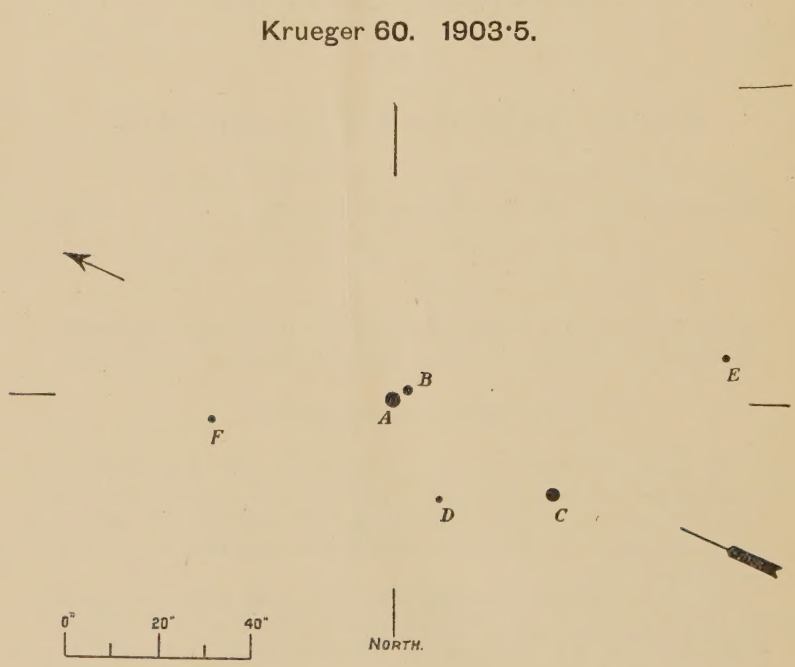


FIG. 1.

measures of A B in that paper there is a misprint of 2″·23 for 3″·23.) In *A.J.*, vol. xxiii.* pp. 169–172, I have given more observations, with a diagram showing the probable orbital motion of A B. A few years' measures soon showed that this was really a physical pair in rather rapid orbital motion. I also called attention to the probable proximity of these stars to our solar system. Acting on this last idea, I began in 1900 a series of measures, with the 40-inch telescope, of A and C for the parallax of A.

* On p. 171 in that paper, the motion in right ascension should be – 0ˢ·107 instead of – 1ˢ·606, and on p. 172 the seconds in the right ascension should be 32ˢ·00 instead of 32ˢ·69. In that paper I derived the proper motion 0″·951 in the direction 246°·3.

In the *Astrophysical Journal*, vol. xx. p. 128, for Sept. 1904, Dr. Schlesinger published his results of the parallax of A derived from photographs made with the 40-inch telescope. Dr. Schlesinger found a parallax of about $\frac{1}{4}''$, verifying the prediction of its nearness to us. I will give, later on, his final values for the parallax.

Additional measures are given by Professor Burnham in *Publications of the Yerkes Observatory*, vol. ii., 1903, p. 67.

This is briefly the history of this remarkable stellar system.

In May of 1903 I measured the position of A with respect to Helsingfors-Gotha A.G.C. 13177. From the measures the place of A is

$$1903{\cdot}0\ \alpha = \quad 22^{h}\ 24^{m}\ 32^{s}{\cdot}09$$
$$\delta = +57^{\circ}\ 12'\ 38''{\cdot}5$$

Proper motion $-0^{s}{\cdot}107 - 0''{\cdot}382$.

The star is Helsingfors-Gotha A.G.C. 13170.

Determination of the Parallax of A.

The present paper gives an investigation of the parallax of the star A from the visual micrometer measures made with the 40-inch telescope.

The micrometer screw and the tube of the 40-inch are both of steel. I have found from about ten years' experimental measures in the Pleiades (which are soon to be published) that the focus of the 40-inch glass shortens from summer to winter by an extreme change of $\frac{3}{4}$ inch. In the meantime the steel tube shortens $\frac{1}{2}$ inch. The temperature change in the micrometer screw will correct $\frac{1}{2}$ inch of the total change of the focus of the object-glass. There remains uncorrected, therefore, $\frac{1}{4}$ inch of the extreme focal change. The exact amount of this uncorrected change, from the measures of the Pleiades referred to above, is 0·0032 inch (0·081 mm.) for each degree of temperature. This would cause an extreme error in the measures of Krueger 60 for temperature of not quite $0''{\cdot}01$, and in the main it would not be appreciable. I have, therefore, not thought it necessary to correct the observations for temperature changes. I have not felt sure that the correction would be real. The corrections for aberration, being insensible, have been omitted.

All of the calculations for the parallax of this star were made, under my supervision, by my niece, Miss Mary Ross Calvert, who, through the courtesy of Mr. Andrew Carnegie, is at present my assistant. They have been carefully checked throughout, and seem to be free from errors. The observations, corrected for refraction, were first freed from proper motion. The parallax factors were then computed by Bessel's formulæ, as given in Chauvenet, vol. i. p. 695, fifth edition, where the parallax factor is

$$Rm \cos (\odot - M),$$

in which R and ⊙ are the distance and longitude of the Sun; m and M being derived from the formulæ

$$m \cos M = \sin \alpha \sin P + \cos \alpha \sin \delta \cos P$$
$$m \sin M = (-\cos \alpha \sin P + \sin \alpha \sin \delta \cos P) \cos \omega - \cos \delta \cos P \sin \omega^*$$

where P is the position-angle of the stars, α and δ the right ascension and declination, and ω the obliquity of the ecliptic.

The formula

$$n + ax + by + cp = 0$$

was used for the equations of condition. In all, there were seventy-six equations of condition. From these the normal equations were derived in the usual manner. The normal equations were solved by the ordinary methods of elimination. As a check, they were also solved by Chauvenet's "second method of computing the weights of unknown quantities" (Chauvenet, vol ii., art. 35, p. 516), from which the weights were also derived. From these last, the probable errors were computed by the formulæ.

Probable error of parallax

$$= \frac{P}{\sqrt{wp}}$$

where wp is the weight of the parallax and

$$P = \pm 0{\cdot}6745 \sqrt{\frac{\Sigma v^2}{n-3}},$$

v being the residuals derived by substituting the known values of x, y, and p in the equations of condition. Similarly for the probable errors of x and y, using for them the same value of P.

This method of determining the probable errors was kindly communicated to me by Dr. Schlesinger.

The proper motion used in these calculations was derived by me from a comparison with Professor Burnham's measures of A C in 1890 and my measures in the last of 1905. This value was $0''{\cdot}968$ in the direction $246°{\cdot}49$.

The corrections for motion, to the observed distances, were computed by the formulæ given on page 696, vol. i., of Chauvenet's *Theoretical and Practical Astronomy*.

In Table I. are given the observations and their reduction to 1901·0, the last column being the residuals from the mean of the corrected distances. Table II. contains the equations of condition.

* We have found that this last term is incorrectly given in Bessel's original paper, *A.N.* 366, pp. 83–84, as $-\sin \delta \cos P \sin \omega$.

The same error occurs in the second of the formulæ for determining the parallax from the position-angle on the same page of *A.N.*, 366, the last term of which should also be $-\cos \delta \cos P \cos \omega$.

TABLE I.

Reductions to 1901·0.

			Pos. Ang.	Dist.	Cor'n for motion.	1901·0.	Resid. from mean.
			°	″	″	″	″
1900·937	Dec.	8	59·27	36·88	+0·061	36·941	−0·423
·940		9	59·52	36·67	+0·058	36·728	−0·210
·945		11	59·25	36·69	+0·053	36·743	−0·225
·948		12	59·16	36·66	+0·050	36·710	−0·192
1901·729	Sept.	23	59·65	37·18	−0·700	36·480	+0·038
·731		24	59·84	37·20	−0·702	36·498	+0·020
·748		30	59·86	37·30	−0·719	36·581	−0·063
·751	Oct.	1	59·52	37·15	−0·722	36·428	+0·090
·783		13	59·63	37·43	−0·752	36·678	−0·160
·805		21	59·48	37·36	−0·774	36·586	−0·068
·827		29	59·49	37·34	−0·795	36·545	−0·027
1902·744	Sept.	29	59·64	38·29	−1·676	36·614	−0·096
·764	Oct.	6	59·69	38·10	−1·695	36·405	+0 113
·766		7	59·64	38·32	−1·697	36·623	−0·105
·786		14	59·60	38·50	−1·716	36·784	−0·266
1903·380	May	19	59·55	38·61	−2·287	36·323	+0·195
·396		25	59·57	38·69	−2·302	36·388	+0·130
·418	June	2	58·89	38·84	−2·323	36·517	+0·001
·437		9	59·18	38·76	−2·342	36·418	+0·100
·454		15	59·35	38·71	−2·358	36·352	+0·166
·473		22	59·59	38·74	−2·376	36·364	+0·154
·492		29	59·57	38·74	−2·394	36·346	+0·172
·495		30	59·22	38·71	−2·397	36·313	+0·205
·511	July	6	59·54	38·84	−2·413	36·427	+0·091
·514		7	59·70	38·71	−2·416	36·294	+0·224
·530		13	59·67	38·73	−2·431	36·299	+0·219
·533		14	59·50	38·78	−2·434	36·346	+0·172
·549		20	59·50	38·88	−2·449	36·431	+0·087
·552		21	59·72	38·76	−2·452	36·308	+0·021
·569	July	27	59·35	38·70	−2·468	36·232	+0·286
·590	Aug.	4	59·57	38·72	−2·489	36·231	+0·287
·607		10	59·33	38·86	−2·505	36·355	+0·163
·626		17	59·61	38·88	−2·523	36·357	+0·161
·645		24	59·84	39·02	−2·541	36·479	+0·039
·664		31	59·60	39·07	−2·560	36·510	+0·008
·667	Sept.	1	59·72	39·20	−2·563	36·637	−0·119
·725		22	59·81	39·31	−2·618	36·692	−0·174

TABLE I.—*Reductions to* 1901·0—continued.

			Pos. Ang.	Dist.	Cor'n for motion.	1901·0.	Resid. from mean.
			°	″	″	″	″
1903·741	Sept.	28	60·02	39·20	−2·634	36·566	−0·048
·757	Oct.	5	59·66	39·37	−2·649	36·721	−0·203
·782		13	59·74	39·37	−2·673	36·697	−0·179
·799		19	59·99	39·45	−2·689	36·761	−0·243
·818		26	59·50	39·38	−2·708	36·672	−0·154
·821		27	59·71	39·48	−2·711	36·769	−0·251
·827	Nov.	2	59·53	39·41	−2·726	36·684	−0·166
·897		24	59·45	39·66	−2·784	36·876	−0·358
·974	Dec.	22	59·40	39·61	−2·858	36·752	−0·234
1904·007	Jan	3	59·05	39·76	−2·889	36·871	−0·353
·335	May	2	59·02	39·73	−3·205	36·525	−0·007
·338		3	59·03	39·48	−3·207	36·273	+0·245
·374		16	58·73	39·50	−3·242	36·258	+0·260
·393		23	59·17	39·55	−3·260	36·290	+0·228
·434	June	7	59·16	39·78	−3·300	36·480	+0·038
·502	July	2	58·91	39·62	−3·365	36·255	+0·263
·521		9	59·34	39·62	−3·383	36·237	+0·281
·527		11	59·27	39·73	−3·389	36·341	+0·177
·560		23	59·47	39·80	−3·421	36·379	+0·139
·570		27	59·41	39·78	−3·430	36·350	+0·168
·584	Aug.	1	59·74	39·74	−3·444	36·296	+0·222
·598		6	59·51	39·69	−3·457	36·233	+0·285
·603		8	59·64	39·76	−3·462	36·298	+0·220
·623		15	59·30	39·85	−3·481	36·369	+0·149
·642		22	59·60	40·04	−3·499	36·541	−0·023
·655		27	59·69	40·08	−3·512	36·568	−0·050
·661		29	59·77	39·95	−3·518	36·432	+0·086
·675	Sept.	3	59·29	40·03	−3·531	36·499	+0·019
·680		5	59·57	40·12	−3·536	36·584	−0·066
·732		24	59·79	40·10	−3·586	36·514	+0·004
·751	Oct.	1	59·43	40·22	−3·604	36·616	−0·098
·790		15	59·87	40·25	−3·642	36·608	−0·090
·795		17	59·68	40·19	−3·647	36·543	−0·025
·828		29	59·59	40·25	−3·678	36·572	−0·054
·833		31	59·62	40 40	−3·683	36·717	−0·199
·866	Nov.	12	59·26	40·53	−3·715	36·815	−0·297
1904·905		26	59·33	40·56	−3·752	36·808	−0·290
1905·904	Nov.	26	59 70	41·46	−4·605	36·855	−0·337
·910		28	59·55	41·38	−4·611	36·769	−0·251

TABLE II.

Equations of Condition.

For x.

1900 Dec.	8.	$-0''.423 + x - 0''.063\,y + 0''.939\,p = 0$
	9.	$-0''.210 + x - 0''.060\,y + 0''.944\,p = 0$
	11.	$-0''.225 + x - 0''.055\,y + 0''.951\,p = 0$
	12.	$-0''.192 + x - 0''.052\,y + 0''.966\,p = 0$
1901 Sept.	23.	$+0''.038 + x + 0''.729\,y - 0''.032\,p = 0$
	24.	$+0''.020 + x + 0''.731\,y - 0''.011\,p = 0$
	30.	$-0''.063 + x + 0''.748\,y + 0''.091\,p = 0$
Oct.	1.	$+0''.090 + x + 0''.751\,y + 0''.102\,p = 0$
	13.	$-0''.160 + x + 0''.783\,y + 0''.303\,p = 0$
	21.	$-0''.068 + x + 0''.805\,y + 0''.427\,p = 0$
	29.	$-0''.027 + x + 0''.827\,y + 0''.545\,p = 0$
1902 Sept.	29.	$-0''.096 + x + 1''.744\,y + 0''.068\,p = 0$
Oct.	6.	$+0''.113 + x + 1''.764\,y + 0''.184\,p = 0$
	7.	$-0''.105 + x + 1''.766\,y + 0''.201\,p = 0$
	14.	$-0''.266 + x + 1''.786\,y + 0''.314\,p = 0$
1903 May	19.	$+0''.195 + x + 2''.380\,y - 0''.826\,p = 0$
	25.	$+0''.130 + x + 2''.396\,y - 0''.884\,p = 0$
June	2.	$+0''.001 + x + 2''.418\,y - 0''.936\,p = 0$
	9.	$+0''.100 + x + 2''.437\,y - 0''.986\,p = 0$
	15.	$+0''.166 + x + 2''.454\,y - 0''.997\,p = 0$
	22.	$+0''.154 + x + 2''.473\,y - 1''.006\,p = 0$
	29.	$+0''.172 + x + 2''.492\,y - 1''.002\,p = 0$
	30.	$+0''.205 + x + 2''.495\,y - 1''.010\,p = 0$
July	6.	$+0''.091 + x + 2''.511\,y - 0''.990\,p = 0$
	7.	$+0''.224 + x + 2''.514\,y - 0''.983\,p = 0$
	13.	$+0''.219 + x + 2''.530\,y - 0''.952\,p = 0$
	14.	$+0''.172 + x + 2''.533\,y - 0''.952\,p = 0$
	20.	$+0''.087 + x + 2''.549\,y - 0''.914\,p = 0$
	21.	$+0''.210 + x + 2''.552\,y - 0''.902\,p = 0$
	27.	$+0''.286 + x + 2''.569\,y - 0''.858\,p = 0$
Aug.	4.	$+0''.287 + x + 2''.590\,y - 0''.775\,p = 0$
	10.	$+0''.163 + x + 2''.607\,y - 0''.712\,p = 0$
	17.	$+0''.161 + x + 2''.626\,y - 0''.620\,p = 0$
	24.	$+0''.039 + x + 2''.645\,y - 0''.519\,p = 0$
	31.	$+0''.008 + x + 2''.664\,y - 0''.417\,p = 0$
Sept.	1.	$-0''.119 + x + 2''.667\,y - 0''.400\,p = 0$
	22.	$-0''.174 + x + 2''.725\,y - 0''.055\,p = 0$
	28.	$-0''.048 + x + 2''.741\,y + 0''.050\,p = 0$

TABLE II.—*Equations of Condition—For* x—continued.

1903 Oct.	5.	$-0\cdot203 + x + 2\cdot757\,y + 0\cdot164\,p = 0$
	13.	$-0\cdot179 + x + 2\cdot782\,y + 0\cdot295\,p = 0$
	19.	$-0\cdot243 + x + 2\cdot799\,y + 0\cdot394\,p = 0$
	26.	$-0\cdot154 + x + 2\cdot818\,y + 0\cdot495\,p = 0$
	27.	$-0\cdot251 + x + 2\cdot821\,y + 0\cdot510\,p = 0$
Nov.	2.	$-0\cdot166 + x + 2\cdot837\,y + 0\cdot595\,p = 0$
	24.	$-0\cdot358 + x + 2\cdot897\,y + 0\cdot839\,p = 0$
Dec.	22.	$-0\cdot234 + x + 2\cdot974\,y + 0\cdot977\,p = 0$
1904 Jan.	3.	$-0\cdot353 + x + 3\cdot007\,y + 0\cdot960\,p = 0$
May	2.	$-0\cdot007 + x + 3\cdot335\,y - 0\cdot638\,p = 0$
	3.	$+0\cdot245 + x + 3\cdot338\,y - 0\cdot651\,p = 0$
	16.	$+0\cdot260 + x + 3\cdot374\,y - 0\cdot801\,p = 0$
	23.	$+0\cdot228 + x + 3\cdot393\,y - 0\cdot879\,p = 0$
June	7.	$+0\cdot038 + x + 3\cdot434\,y - 0\cdot980\,p = 0$
July	2.	$+0\cdot263 + x + 3\cdot502\,y - 1\cdot003\,p = 0$
	9.	$+0\cdot281 + x + 3\cdot521\,y - 0\cdot973\,p = 0$
	11.	$+0\cdot177 + x + 3\cdot527\,y - 0\cdot967\,p = 0$
	23.	$+0\cdot139 + x + 3\cdot560\,y - 0\cdot886\,p = 0$
	27.	$+0\cdot168 + x + 3\cdot570\,y - 0\cdot855\,p = 0$
Aug.	1.	$+0\cdot222 + x + 3\cdot584\,y - 0\cdot799\,p = 0$
	6.	$+0\cdot285 + x + 3\cdot598\,y - 0\cdot747\,p = 0$
	8.	$+0\cdot220 + x + 3\cdot603\,y - 0\cdot723\,p = 0$
	15.	$+0\ 149 + x + 3\cdot623\,y - 0\cdot640\,p = 0$
	22.	$-0\cdot023 + x + 3\cdot642\,y - 0\cdot511\,p = 0$
	27.	$-0\cdot050 + x + 3\cdot655\,y - 0\cdot467\,p = 0$
	29.	$+0\cdot086 + x + 3\cdot661\,y - 0\cdot434\,p = 0$
Sept.	3.	$+0\cdot019 + x + 3\cdot675\,y - 0\cdot364\,p = 0$
	5.	$-0\cdot066 + x + 3\cdot680\,y - 0\cdot326\,p = 0$
	24.	$+0\cdot004 + x + 3\cdot732\,y - 0\cdot007\,p = 0$
Oct.	1.	$-0\cdot098 + x + 3\cdot751\,y + 0\cdot105\,p = 0$
	15.	$-0\cdot090 + x + 3\cdot790\,y + 0\cdot342\,p = 0$
	17.	$-0\cdot025 + x + 3\cdot795\,y + 0\cdot373\,p = 0$
	29.	$-0\cdot054 + x + 3\cdot828\,y + 0\cdot548\,p = 0$
	31.	$-0\cdot199 + x + 3\cdot833\,y + 0\cdot578\,p = 0$
Nov.	12.	$-0\cdot297 + x + 3\cdot866\,y + 0\cdot726\,p = 0$
	26.	$-0\cdot290 + x + 3\cdot905\,y + 0\cdot862\,p = 0$
1905 Nov.	26.	$-0\cdot337 + x + 4\cdot904\,y + 0\cdot863\,p = 0$
	28.	$-0\cdot251 + x + 4\cdot910\,y + 0\cdot875\,p = 0$
		$+0\cdot011 + 76x + 204\cdot053y - 14\cdot804\,p = 0$

Corresponding equations were deduced for y and p, the resulting normal equations being

$$+0\cdot0110+\ 76\cdot000\,x+204\cdot0530\,y-14\cdot8040\,p=0$$
$$+2\cdot2742+204\cdot053\,x+642\cdot2801\,y-52\cdot9454\,p=0$$
$$-8\cdot5866-\ 14\cdot804\,x-\ 52\cdot9454\,y+38\cdot0005\,p=0$$

The solution of these gives the following values :—

$$p=+0''\cdot249\pm0''\cdot0105$$
$$y=+0\cdot011\pm0\cdot0063$$
$$x=+0\cdot020\pm0\cdot0182.$$

The value of the parallax of the star A is, therefore,

$$\pi=+0''\cdot249\pm0''\cdot0105.$$

This gives a distance of over 830,000 times that of the Sun. Light, therefore, requires 13·1 years to come from Krueger 60.

Dr. Schlesinger has kindly supplied me with his final value for the parallax of this star. He determined the parallax by photography (during his connection with the Yerkes Observatory) from both right ascension and declination. These were from 19 plates taken with the 40-inch telescope from 1903 to 1906. Three separate images were impressed on each plate. His results are—

$$\text{From R.A. } \pi=+0''\cdot257\pm0''\cdot007$$
$$\text{,, Decl. } \pi=+0\cdot238\pm0\cdot011.$$

It will be seen that the mean of these,

$$\pi=+0''\cdot248,$$

is essentially identical with my value.

The results with the same instrument, by visual and photographic methods respectively, in the one case by position-angle and distance, and in the other by right ascension and declination, should inspire confidence in both methods.

Irregularity in the Proper Motion of A.

At present the stars A and B are moving almost directly away from C. This latter star, therefore, is a good one from which to determine the motion.

If B has a considerable mass ratio to A, a large irregularity in the proper motion of either star must occur because of the large apparent distance between the two. If their masses should be nearly equal, this deviation from uniformity of motion in either star may amount to as much as 1″·5. This last mass ratio is not

improbable, in view of the investigations of Mr. Lewis of the Greenwich Observatory who found * that in some cases the apparently smaller star of a binary is really the more massive of the two. It is important, therefore, frequently to measure the position of A with reference to C and other stars in the field. By this means, in the course of time, its mass will become accurately known. For this reason I have kept the star on my observing list, and have made frequent measures of it and the stars mentioned. Of my own work there are now some seven or eight years' observations. Of course, for various reasons, where it is possible, it is best to use the measures of one individual.

The known history of these stars perhaps covers too short an interval for the observations to show any very decided irregularity in the motion of A. To see if there was any such change, the measures were freed from parallax, and means of four or five taken. These were plotted on a large scale. A thread was then tightly stretched over the measures and carefully adjusted to give the best representation. This straight line does not represent the observations with entire satisfaction. The best average, however, was obtained, and the deviations read off. These differences are given in connection with the mean measures. The ends of the thread would represent the positions 1900·943, distance 36″·49, and 1908·302, distance 43″·53.

As these measures may be of interest to others, they are given below. The first column after the dates is the measured distance corrected for refraction, the next column gives the correction for parallax, while the last is the distance affected only by motion. The means of these and their deviation from the straight line are also given.

Distances (A C) *corrected for parallax.*

			Obs. dist.	Cor'n for pllx.	True dist.	
			″	″	″	
1900	Dec.	8	36·88	−0·23	36·65	
		9	36·67	−0·23	36·44	
		11	36·69	−0·24	36·45	
		12	36·66	−0·24	36·42	
1900·943					36·49	− 0″·01
1901	Sept.	23	37·18	+0·01	37·19	
		24	37·20	0·00	37·20	
		30	37·30	−0·02	37·28	
	Oct	1	37·15	−0·03	37·12	
1901·740					37·20	− 0·04
1901	Oct.	13	37·43	−0·08	37·35	
		21	37·36	−0·11	37·25	
		29	37·34	−0·14	37·20	
1901·792					37·27	− 0·02

* *Memoirs R.A.S.*, vol. lvi. p. xxi.

Distances (A C) *corrected for parallax*—continued.

		Obs. dist.	Cor'n for pllx.	True dist.	
1902	Sept. 29	38″·29	−0″·02	38″·27	
	Oct. 6	38·10	−0·04	38·06	
	7	38·32	−0·05	38·27	
	14	38·50	−0·08	38·42	
1902·764				38·25	+ 0″·01
1903	May 19	38·61	+0·21	38·82	
	25	38·69	+0·22	38·91	
	June 2	38·84	+0·23	39·07	
	9	38·76	+0·25	39·01	
1903·407				38·95	+ 0·10
1903	June 15	38·71	+0·25	38·96	
	22	38·74	+0·25	38·99	
	29	38·74	+0·25	38·99	
	30	38·71	+0·25	38·96	
1903·480				38·97	+ 0·05
1903	July 6	38·84	+0·25	39·09	
	7	38·71	+0·24	38·95	
	13	38·73	+0·24	38·97	
	14	38·78	+0·24	39·02	
1903·524				39·01	+ 0·04
1903	July 20	38·88	+0·23	39·11	
	21	38·76	+0·22	38·98	
	27	38·70	+0·21	38·91	
	Aug. 4	38·72	+0·19	38·91	
1903·568				38·98	0·00
1903	Aug. 10	38·86	+0·18	39·04	
	17	38·88	+0.15	39·03	
	24	39·02	+0·13	39·15	
	31	39·07	+0·10	39·17	
1903·637				39·10	+ 0·03
1903	Sept. 1	39·20	+0·10	39·30	
	22	39·31	+0·01	39·32	
	28	39·20	−0·01	39·19	
	Oct. 5	39·37	−0·04	39·33	
1903·725				39·29	+ 0·14

Distances (A C) *corrected for parallax*—continued.

			Obs. dist.	Cor'n for pllx.	True dist.	
1903	Oct.	13	39″·37	−0″·07	39″·30	
		19	39·45	−0·10	39·35	
		26	39·38	−0·12	39·26	
		27	39·48	−0·13	39·35	
1903·804					39·31	+ 0″·09
1903	Nov.	2	39·41	−0·15	39·26	
		24	39·66	−0·21	39·45	
	Dec.	22	39·61	−0·25	39·36	
1904	Jan.	3	39·76	−0·24	39·52	
1903·927					39·40	+ 0·06
1904	May	2	39·73	+0·16	39·89	
		3	39·48	+0·16	39·64	
		16	39·50	+0·20	39·70	
		23	39·55	+0·22	39·77	
1904·360					39·75	0·00
1904	June	7	39·78	+0·24	40·02	
	July	2	39·62	+0·25	39·87	
		9	39·62	+0·24	39·86	
		11	39·73	+0·24	39·97	
1904·497					39·93	+ 0·04
1904	July	23	39·80	+0·22	40·02	
		27	39·78	+0·21	39·99	
	Aug.	1	39·74	+0·20	39·94	
		6	39·69	+0·19	39·88	
1904·579					39·96	0·00
1904	Aug.	8	39·76	+0·18	39·94	
		15	39·85	+0·16	40·01	
		22	40·04	+0·12	40·16	
		27	40·08	+0·12	40·20	
1904·631					40·08	+ 0·04
1904	Aug.	29	39·95	+0·11	40·06	
	Sept.	3	40·03	+0·09	40 12	
		5	40·12	+0·08	40·20	
		24	40·10	0·00	40·10	
1904·686					40·12	+0·06

Distances (A C) *corrected for parallax*—continued.

		Obs. dist.	Cor'n for pllx.	True dist.	
1904	Oct. 1	40″·22	−0″·03	40″·19	
	15	40·25	−0·08	40·17	
	17	40·19	−0·09	40·10	
	29	40·25	−0·14	40·11	
1904·790				40·14	0″·00
1904	Oct. 31	40·40	−0·14	40·26	
	Nov. 12	40·53	−0·18	40·35	
	26	40·56	−0·21	40·35	
1904·869				40·32	+ 0·09
1905	Nov. 26	41·46	−0·21	41·25	
	28	41·38	−0·22	41·16	
1905·907				41·21	− 0·03
1906	June 28	41·45	+0·25	41·70	
	July 7	41·51	+0·24	41·75	
	10	41·54	+0·24	41·78	
	24	41·76	+0·22	41·98	
1906·523				41·80	− 0·03
1906	July 29	41·68	+0·21	41·89	
	Aug. 11	41·72	+0·17	41·89	
	14	41·63	+0·16	41·79	
1906·602				41·86	− 0·20
1907·289	Apr. 16	42·52	+0·10	42·62	+ 0·10
1907	July 2	42·73	+0·25	42·98	
	12	42·57	+0·24	42·81	
	28	42·63	+0·21	42·84	
	30	42·64	+0·21	42·85	
1907·544				42·87	+ 0·04
1907	Aug. 6	42·77	+0·19	42·96	
	8	42·62	+0·18	42·80	
	11	42·53	+0·17	42·70	
	13	42·78	+0·17	42·95	
	20	42·68	+0·14	42·82	
1907·612				42·85	− 0·01
1907·749	Oct. 1	42·91	−0·03	42·88	− 0·11
1908	Apr. 19	43·40	+0·12	43·52	
	21	43·25	+0·12	43·37	
1908·302				43·44	− 0·08

Proper Motion of the Double Star Krueger 60.

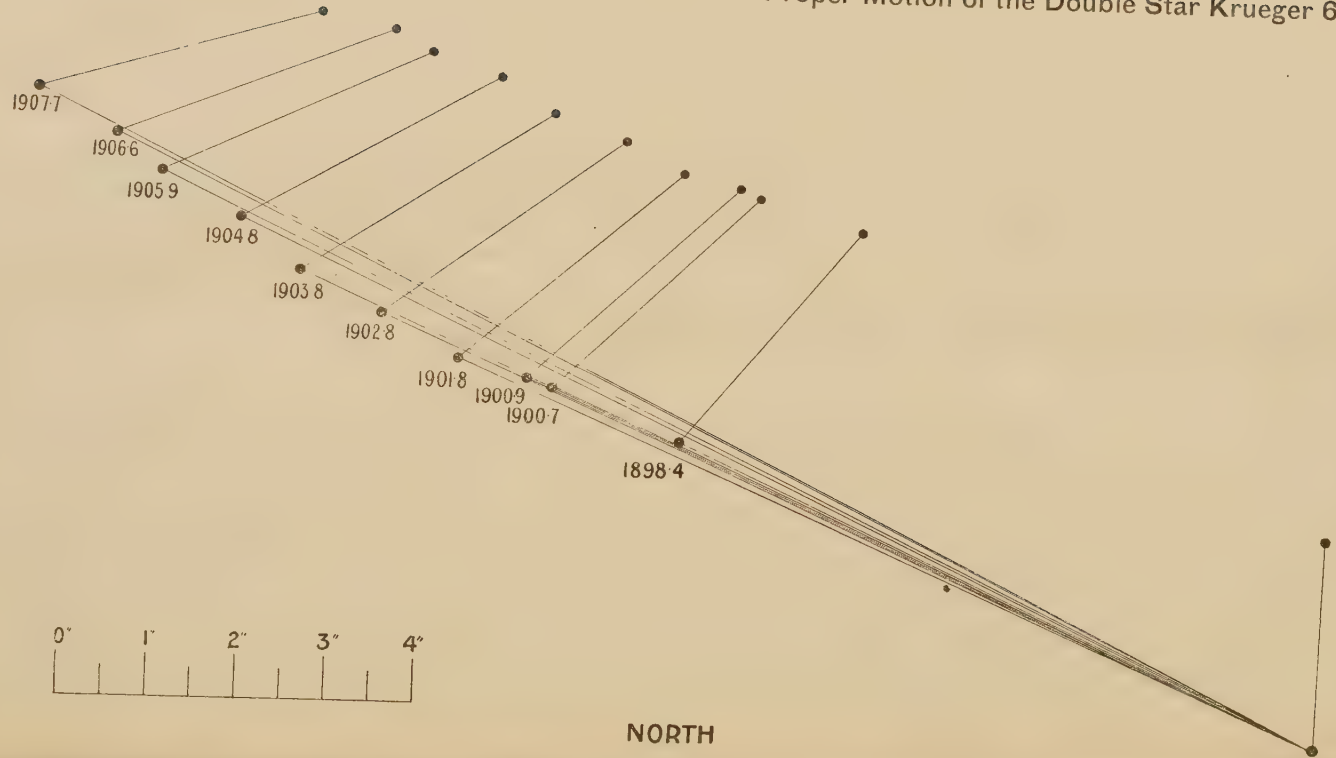


FIG.

This investigation led me to notice that the direction of motion of A was regularly diminishing with the increase of time when derived from a comparison with the measures of 1890·8. The motion was also slightly increasing. To find out the cause of this change I plotted the observations for each year (fig. 2), correcting the distances for parallax, and selecting the positions so that there would be but little parallactic change in the angles. No correction for precession has been applied to the position-angles. The extreme change due to this last cause would be 0°·07. The result shows that between the epochs 1890·8 to 1901·8 and 1901·8 to 1907·7 there has been a total change of some 8° or 9° in the direction of motion. If we take the interval 1901·8–1907·7 the direction of motion is 239°, while the previous values were about 247°. A simple inspection of the diagram will show the change. It is evident, therefore, that the motion of A is not rectilinear. This change is undoubtedly due to the orbital motion of A about the centre of gravity of the system. It is therefore not possible to give a value of its proper motion that will be constant for any considerable interval of time.

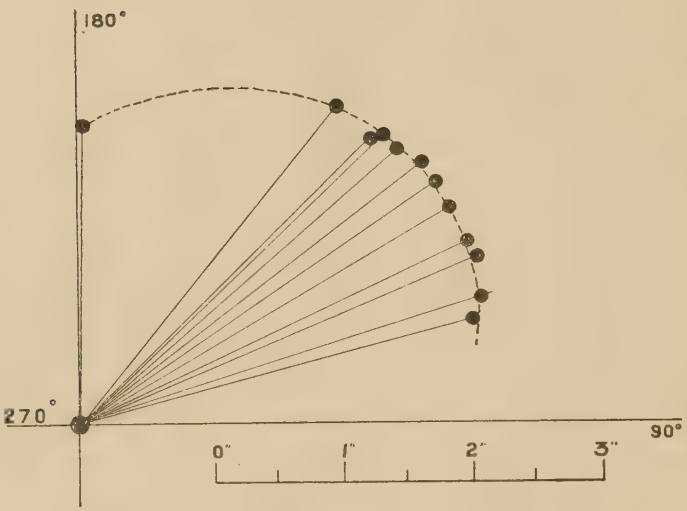
The following measures were used in constructing the diagram. The distances A C are corrected for parallax.

A C.

	°	″	Observer.
1890·788	56·30	26·73	Burnham.
1898·446	58·71	34·64	Doolittle.
1900·737	59·19	36·18	,,
1900·943	59·30	36·49	Barnard.
1901·766	59·62	37·23	,,
1902·764	59·64	38·25	,,
1903·765	59·77	39·30	,,
1904·782	59·55	40·19	,,
1905·907	59·63	41·21	,,
1906·602	59·54	41·86	,,
1907·680	59·57	42·87	,,

A B.

		″	Observer.
1890·788	178·80	2·32	Burnham.
1898·446	140·66	3·19	Doolittle.
1900·737	134·02	3·18	,,
1900·943	133·14	3·25	Barnard.
1901·767	130·67	3·28	,,
1902·765	127·05	3·36	,,
1903·761	123·89	3·35	,,
1904·791	120·30	3·33	,,
1905·907	115·34	3·31	,,
1906·601	112·27	3·34	,,
1907·676	107·00	3·27	,,



Orbital Motion of Krueger 60.

FIG. 3.

The Micrometer Measures.

I have collected here for this paper all my published and unpublished measures of these stars, so that my work on the subject up to the present may be presented as completely as possible. All the distances have been corrected for refraction.

The diagram (fig. 1) will show the relative positions of these various stars.

The measures follow.

Measures of Krueger 60 and Comparison Stars.

A B.

		°	"	mag.	mag.
1900·937 Dec.	8	132·06	3·30	9·2	10·5
·940	9	133·19	3·25		
·945	11	133·59	3·24		
·948	12	133·71	3·23		
1900·943		133·14	3·25	9·2	10·5

A B—*continued.*

					mag.	mag.
1901·729	Sept.	23	130°·05	3″·37		
·731		24	129·11	3·39	9·5	10·5
·748		30	131·50	3·37		
·751	Oct.	1	131·65	3·25		
·783		13	129·69	3·31		
·805		21	130·59	3·26	9·2	10·5
·827		29	130·59	3·22		
1901·768			130·45	3·31	9·3	10·5
1902·744	Sept.	29	127·25	3·33		
·764	Oct.	6	128·17	3·43		
·766		7	126·73	3·35		
·785		14	126·06	3·35		
1902·765			127·05	3·37		
1903·380	May	19	122·36	3·32		
·418	June	2	122·34	3·42		
·437		9	123·85	3·40		
·454		15	123·49	3·37		
·473		22	123·47	3·33		
·492		29	124·90	3·36		
·495		30	125·96	3·26		
·511	July	6	121·31	3·51		
·514		7	123·18	3·30		
645	Aug.	24	124·52	3·45		
·664		31	122·91	3·35		
·667	Sept.	1	121·98	3·37		
·725		22	124·54	3·27		
·741		28	123·54	3·45		
·818	Oct.	26	123·60	3·33		
1903·562			123·46	3·37		

A B—*continued.*

			°	″	mag.	mag.
1904·335	May	2	119·44	3·35		
·338		3	119·46	3·35		
·373		16	119·92	3·40		
·393		23	118·51	3·43		
·434	June	7	118·82	3·37		
·502	July	2	121·45	3·43		
·521		9	121·28	3·35		
·527		11	120·68	3·31		
·560		23	119·94	3·39		
·570		27	117·99	3·35		
·584	Aug.	1	120·47	3·43		
·598		6	119·24	3·48		
·642		22	120·96	3·42		
·655		27	119·47	3·37		
·675	Sept.	3	119·50	3·41		
·751	Oct.	1	118·98	3·31		
·795		17	121·07	3·28		
·828		29	120·84	3·39		
·905	Nov.	26	117·46	3·33		
1904·578			119·76	3·38		
1905·904	Nov.	26	116·04	3·30		
·910		28	114·64	3·31		
1905·907			115·34	3·31		
1906·490	June	28	113·63	3·28		
·515	July	7	112·44	3·28		
·523		10	109·72	3·34		
·561		24	112·57	3·33		
·575		29	112·71	3·31		
·610	Aug.	11	112·31	3·33		
·619		14	111·78	3·38		
1906·556			112·17	3·32		

A B—*continued.*

			mag.	mag.
1907·289 Apr. 16	108°·06	3″·14		
·500 July 2	108·09	3·26		
·528 12	106·31	3·29		
·571 28	106·59	3·28		
·577 30	107·83	3·23		
·596 Aug. 6	106·06	3·42		
·601 8	107·92	3·28		
·610 11	106·93	3·38		
·615 13	107·47	3·20		
·634 20	107·13	3·17		
·706 Sept. 15	105·34	3·37		
·749 Oct. 1	108·06	3·36		
1907·581	107·15	3·28		
1908·300 Apr. 19	105·65	2·97		
·338 May 3	105·19	3·30		
·376 17	103·99	3·21		
·382 19	104·63	3·23		
·390 22	104·18	3·26		
·401 26	102·70	3·13		
1908·373	104·39	3·18		

A C

In this table all the previous measures of A C—those used in the determination of the parallax—have been omitted, because they are given in Table I.

			mag.	mag.
1906·490 June 28	59°·01	41″·45		
·515 July 7	59·23	41·49		
·523 10	59·23	41·54		
·561 24	59·71	41·76		
·575 29	59·55	41·68		
·610 Aug. 11	59·60	41·72		9·5
·619 14	59·48	41·63		
1906·556	59·40	41·61		9·5

A C—*continued.*

				mag.	mag.
1907·289	Apr. 16	59°18	42″52		
·500	July 2	59·34	42·73		
·528	12	59·55	42·57		
·571	28	59·40	42·63		
·577	30	59·19	42·64		
·596	Aug. 6	59·44	42·77		
·601	8	59·59	42·62		
·610	11	59·14	42·53		
·615	13	59·50	42·78		
·634	20	59·55	42·68		
·749	Oct. 1	59·71	42·91		
1907·570		59·42	42·67		
1908·300	Apr. 19	59·32	43·41		
·305	21	58·99	43·25		
·338	May 3	58·76	43·51		
·357	10	59·15	43·72		
·376	17	58·98	43·32		
·382	19	59·24	43·52		
·390	22	58·98	43·57		
·401	26	59·19	43·54		
1908·356		59·08	43·48		

A D.

1900·945	Dec. 11	21°25	21″26		15
·948	12	20·86	21·34		15·5
1900·947		21·05	21·30		15·3
1901·783	Oct. 13	23·56	21·54		15
·786	14	21·58	21·85		
·805	21	23·04	21·72		15·3
·827	29	23·07	21·78		
1901·800		22·81	21·72		15·1
1903·511	July 6	24·68	22·75		
·514	7	24·09	22·83		15
1903·512		24·39	22·79		15
1908·415	May 31	29·25	26·69		
·467	June 19	29·51	26·99		
·472	21	29·48	26·93		
1908·451		29·41	26·87		

A E.

				mag.	mag.
1900·937	Dec. 8	98°·85	68″·03		12·5
·940	9	99·06	67·79		13·5
·945	11	99·00	67·76		13·5
1900·941		98·97	67·86		13·2
1901·729	Sept. 23	98·93	68·20		12
·731	24	99·14	68·49		12·5
·748	30	99·06	68·64		
·751	Oct. 1	98·92	68·22		
·783	13	99·01	68·32		
·805	21	98·91	68·39		11·3
·827	29	98·83	68·64		
1901·768		98·97	68·41		11·9
1903·437	June 9	97·89	69·17		13
·454	15	97·99	69·37		
·473	22	97·87	69·20		12
·495	30	97·96	69·42		
·511	July 6	98·07	69·47		
·514	7	97·78	69·51		
·530	13	98·26	69·38		
·533	14	98·18	69·44		
·549	20	98·09	69·55		
·569	27	98·01	69·47		
·607	Aug. 10	97·64	69·44		
·626	17	97·84	69·64		
·645	24	97·97	69·90		
·664	31	97·86	69·72		
·667	Sept. 1	97·93	69·71		
·725	22	98·02	70·12		
·741	28	97 90	69·89		12
·757	Oct. 5	97·86	69·93		
·782	13	97·59	70·11		
·799	19	97·80	70·26		13
·818	26	97·78	70·22		
·821	27	97·70	70·08		12·5
·837	Nov. 2	97·64	70·11		12
·897	24	97·56	70·26		12
·974	Dec. 22	97·41	70·22		12
1904·007	Jan. 3	97·49	70·47		12
1903·670		97·85	69·81		12·3

A E—*continued.*

				mag.	mag.
1904·335	May 2	97°·14	70″·10		12
·338	3	97·44	69·91		12
·527	July 11	97·42	70·38		12
·560	23	97·53	70·19		12
·570	27	97·43	70·13		13
·584	Aug. 1	97·64	70·21		13
·598	6	97·32	70·47		
·603	8	97·89	70·76		
·623	15	97·66	70·76		
·642	22	97·54	70·49		12
·655	27	97·50	70·61		13
·661	29	97·56	70·93		
·675	Sept. 3	97·44	70·61		12
·680	5	97·66	70·81		12·5
·751	Oct. 1	97·53	70·80		12·5
·790	15	97·54	71·00		12
·795	17	97·40	70·77		12
·828	29	97·48	70·97		12·5
·833	31	97·27	70·99		12·8
·866	Nov. 12	97·23	71·06		
·905	26	97·29	70·94		12
1904·653		97·47	70·61		12·3
1905·910	Nov. 28	96·87	71·97		
1906·610	Aug. 11	97·08	72·04		12·5
·619	14	96·61	72·20		12·5
1906·615		96·85	72·12		12·5
1907·596	Aug. 6	96·04	72·51		13
·601	8	95·96	72·66		
·610	11	95·70	72·80		
·615	13	96·29	72·80		
·634	20	95·93	72·59		
·667	Sept. 1	95·82	72·88		12·8
·706	15	96·24	72·89		
·749	Oct. 1	96·14	72·80		
1907·647		96·01	72·74		12·9

A E—*continued.*

				mag.	mag.
1908·415	May 31	95°·53	73″·05		
·417	June 1	95·39	73·00		
·428	5	95·47	73·10		
·467	19	95·41	73·14		
·472	21	95·50	73·08		
1908·440		95·46	73·07		

A F.

1901·729	Sept. 23	275°·36	39″·61		14
·731	24	274·78	39·53		14
·751	Oct. 1	275·20	39·61		
·784	13	275·33	39·52		15
·805	21	275·34	39·53		15
·827	29	275·53	39·57		
1901·771		275·26	39·56		14·5

1903·473	June 22	277°·24	38″·47		13
·492	29	277·59	...		13 clouds.
·495	30	276·84	38·46		12·7
·511	July 6	277·06	38·34		12
·514	7	277·09	38·51		
·533	14	276·52	38·37		
·549	20	276·34	38·50		
·626	Aug. 17	276·92	38·45		
·645	24	276·49	38·11		
·664	31	276·70	38·21		
·725	Sept. 22	276·74	38·16		
·741	28	276·87	37·80		15
·782	Oct. 13	277·06	38·15		
·799	19	277·14	38·07		14·5
·818	26	277·31	38·80		
·821	27	277·36	37·79		15·0
·897	Nov. 24	277·35	38·29		14·5
1903·652		276·98	38·28		13·7

A F—*continued.*

				mag.	mag.
1904·335	May 2	278°·20	37″·76		12·7
·393	23	277·89	38·05		12·5
·560	July 23	277·71	37·39		14
·570	27	277·64	37·62		
·584	Aug. 1	277·36	37·35		15
·598	6	277·01	37·90		
·655	27	277·74	37·15		14
·675	Sept. 3	277·67	37·40		15
·751	Oct. 1	277·84	37·15		14·5
·790	15	278·17	37·38		15
·795	17	277·64	36·83		14·5
·828	29	278·19	37·18		14·7
·833	31	277·87	37·34		14·5
·905	Nov. 26	278·16	36·99		14·5
1904·734		277·79	37·39		14·2
1907·667	Sept. 1	280·56	35·23		14·5
·706	15	280·76	34·47		
·749	Oct. 1	280·75	34·73		14·5
·782	13	281·05	34·67		14
1907·726		281·78	34·77		14·3
1908·415	May 31	281·80	34·94		
·417	June 1	282·06	35·16		
·428	5	282·13	35·15		
·467	19	281·58	34·63		
·472	21	281·40	34·78		
1908·440		281·94	34·93		

C E.

1903·552	July 21	129°·71	46″·19		
1907·634	Aug. 20	129·41	45·84		
·782	Oct. 13	129·88	45·98		13·7
1907·708		129·65	45·91		13·7

It will be seen from the measures that the distance A B is beginning to lessen, having attained a maximum about 1903 or 1904. The position-angle A C seems to have reached its greatest value about 1907 and is now slowly diminishing. Both changes are due to the orbital motion of A in the system A B.

The following estimates of the magnitude of C were made at the time of the observations which have been included in Table I.

	m
1900 Dec. 8	9·5
1901 Sept. 24	9·5
Oct. 21	9·7
1902 Sept. 29	9·9

At the observation of 1900 Dec. 9 the following note occurs:—"Both A and C are slightly yellowish."

Two small Double Stars near Krueger 60.

During these measures two small double stars were found and measured. Though they are not in any way connected with Krueger 60, their proximity to this star, and the general resemblance of one of them to A B, would seem to warrant their insertion here.

No. 1.

(1855·0 α 22^h 19^m 42^s·8, δ +57° 6′·3.)

		°	″	mag.	mag.
1901·731	Sept. 24	247·04	2·99	9·5	12
·805	Oct. 21	247·19	3·11	9	11
1901·768		247·11	3·05	9·3	11·5
1902·766	Oct. 7	247·23	2·67	9·5	11
1903·454	June 15	246·70	3·20	9·8	11
·473	22	248·79	3·09		
·511	July 6	247·62	3·04		
·514	7	246·68	3·25		
1903·488		247·45	3·14	9·8	11
1908·428	June 5	248·05	3·04		
·467	19	245·08	3·22	9·3	11·2
1908·447		246·57	3·13	9·3	11·2

No. 2.

(1903·0 α 22h 22m 52s·1, δ +57° 13′ 33″.)

					mag.	mag.
1902·744	Sept.	29	260°·15	1″·37	10	11
1903·454	June	15	262·50	1·41		
1907·749	Oct.	1	259·05	1·37		
1908·382	May	19	261·32	1·35	10	11
·401		26	260·95	1·45	9·6	10·5
·467	June	19	259·95	1·46		
1908·417			260·74	1·42	9·8	10·7

The Following Component of No. 2 and a Faint Star North.

					mag.	mag.
1908·382	May	19	340°·59	87″·67		12
·401		26	340·56	87·70		13·2
1908·391			340·57	87·69		12·6

Additional measures of some of the stars have been inserted since this paper was submitted to the R.A.S.

YERKES OBSERVATORY:
1908 *May* 18.

Postscript.

I am very glad to be able to add to this paper the value of the parallax of Krueger 60 determined by Dr. Henry Norris Russell from photographs with the Cambridge (England) refractor. Dr. Russell has kindly supplied me with his value since my paper was put in type.

His result is:—

$$\pi = +0''\cdot258 \pm 0''\cdot013$$

from measures of $\Delta\alpha$. Nine comparison stars were used, and the probable error for a single plate was $\pm 0''\cdot026$.

The following, therefore, are all of the values of the parallax of this star known to me:—

Schlesinger = +0″·248 ± 0″·009
Barnard = +0 ·249 ± 0 ·010
Russell = +0 ·258 ± 0 ·013

Photograph containing three exposures of the double star Krueger 60 A B and the comparison star C. Taken with the 40-inch refractor of the Yerkes Observatory, 1908 July 10 (enlarged). Exposures 10 minutes each. —E. E Barnard.

Additional Measures of Krueger 60.

A B.

1908 Aug.	30	100°·71	3″·14
Sept.	4	103·10	3·17
	6	105·13	3·15
	15	104·69	3·24
	20	103·92	3·14
Oct.	4	102·67	3·21
		103·37	3·17

A C.

1908 Aug.	30	59°·62	43″·93
Sept.	4	59·69	43·94
	6	59·55	43·91
	15	59·38	44·19
	20	59·74	43·87
Oct.	4	59·55	44·08
		59·59	43·99

I have also added a photograph of Krueger 60 (A B) and the comparison star C, which I made on 1908 July 10 with the 40-inch refractor and a yellow colour screen, with Cramer Instantaneous Iso plate. There are three exposures of 10^m each.

1908 *Oct.* 5.

On possible Periodic Inequalities in the Epoch of the Sun-spot Variation. Papers of the I.U.S.R. Computing Bureau, No. III.
By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

1. When any point of importance arises with regard to the stars, it is natural to inquire whether it is represented in the behaviour of the one star which we can observe to special advantage, viz. our own Sun. Reasons have been given elsewhere* for regarding the Sun, provisionally at any rate, as a long-period variable with a period of $11\frac{1}{8}$ years, but with a very small range of variation. Reasons have also been given† for regarding the oscillations of maximum of long-period variables as systematic; so that when Chandler writes for the epochs of maximum an expression such as

$$\epsilon + \mathrm{P.E} + \mathrm{C}\sin(\mathrm{A}^{\circ}.\mathrm{E} + \alpha),$$

where P is the period in days, and E the number of periods elapsed since the epoch ϵ, and C, A, α three constants, we have approximately

$$\mathrm{C} = 7^{\mathrm{d}}.3 + .064\ \mathrm{P}$$
$$\mathrm{A} = 2^{\circ}.6 + .018\ \mathrm{P}.$$

Hence the questions arise,—Is there an oscillation of this kind in the Sun-spot maxima? and if so, how far does it fit in with these formulæ? The period of the Sun (say 4060 days) is so very much longer than that of any of the stars used in deriving the above formulæ that we may be prepared for some error, even a considerable error, in the extrapolation; but we may at least expect both A and C to be larger than for the stars, if the Sun falls into line at all.

2. Dr. Wolfer has given (on page 96 of the *Astron. Mitteilungen*, No. xciii.) a list of deviations of 26 minima and 26 maxima from a uniform arithmetical progression. These are shown in Table I.

TABLE I.

Wolfer's Minima and Maxima of Sun-spots.

Min. *y*	Max. *y*	Min. *y*	Max. *y*	Min. *y*	Max. *y*
+0·3	−0·8	+1·2	+2·1	−0·5	+0·5
−2·7	−1·4	+1·6	+0·3	+1·1	+2·9
+1·2	+1·0	+0·9	+0·4	+0·6	−0·9
+1·0	−0·6	+0·8	+0·9	−1·0	−1·1
−0·1	−0·6	−0·2	+1·0	+0·4	−0·2
−0·2	+3·3	0·0	−1·9	+0·4	−0·8
+2·1	+2·2	−2·1	−4·2	+1·0	+1·4
+1·0	−0·9	−4·1	−5·6	+0·5	+0·5
−1·7	+0·5	−1·6	+0·4		

(The unit is one year.)

* See *Mon. Not.*, lxiv. p. 549 and lxvii. p. 334.
† *Mon. Not.*, lxviii. p. 544 (June 1908).

3. The problem is to find whether these residuals are affected with a periodicity C sin (A°.E + a), of which both the coefficient C and the argument A are unknown. In such a case, Professor Schuster has insisted that we have no resource but to try *all* values of A; or rather a series of values separated by small intervals, the size of the interval depending on the "resolving power" of the available material. In the present case, successive values of A differing by 2° were tried, and the resulting "periodogram" shows that this interval is sufficiently small. For each value of A we form

$$a^2 + b^2 \equiv \left(\sum r_E \sin \mathrm{A}^\circ.\mathrm{E}\right)^2 + \left(\sum r_E \cos \mathrm{A}^\circ.\mathrm{E}\right)^2$$

E being used by Chandler to denote the number of periods after a given epoch, and r_E being the corresponding residual in Table I. If we had *exactly*

$$r_E = \mathrm{C} \sin (\mathrm{A}^\circ.\mathrm{E} + a)$$

then we should have

$$a = \mathrm{C}\left[\cos a \sum \sin^2 \mathrm{AE} + \sin a \sum \sin \mathrm{AE} \cos \mathrm{AE}\right]$$

$$= \tfrac{1}{2}\mathrm{C}\left[\cos a \sum (1 - \cos 2\mathrm{AE}) + \sin a \sum \sin 2\mathrm{AE}\right]$$

$$= \tfrac{1}{2}\mathrm{C}\left[n \cos a - \sum \cos (2\mathrm{AE} + a)\right]$$

where n is the number of terms in the series—viz. 26 in our case. Now the sum $\Sigma \cos (2\mathrm{AE} + a)$ is generally small compared with n. It will be seen later that the smallest value of A which seriously concerns us is about 20°; so that as E increases from 0 to 26, 2AE increases from 0° to $40^\circ \times 26 = 3 \times 360^\circ$ nearly. Hence cos (2AE + a) runs through its cycle nearly three times; and since in each cycle the positive and negative terms cut one another out, what is left is small. Neglecting it, we should have, in the ideal case,

$$a = \tfrac{1}{2}\mathrm{C}\, n \cos a \qquad \text{and} \qquad b = \tfrac{1}{2}\mathrm{C}\, n \sin a$$

$$\text{or} \qquad 13\mathrm{C} = \sqrt{a^2 + b^2}.$$

But accidental errors will give a sensible value for $a^2 + b^2$ for any value of A. We must look for values of A which give *large* values of $a^2 + b^2$. These values are tabulated in Table II., which was calculated in the Computing Bureau of the I.U.S.R.

TABLE II.

Periodogram of Wolfer's Residuals.

A	Min.	Max.	A	Min.	Max.	A	Min.	Max.
°								
2	·00	·04	48	1·06	1·97	94	1·04	1·08
4	·01	·09	50	1·01	2·81	96	·92	·92
6	·07	·16	52	1·05	3·52	98	·75	·80
8	·26	·39	54	·95	3·34	100	·82	·53
10	·33	·70	56	·66	2·98	102	·72	·28
12	·45	·99	58	·43	2·57	104	·66	·46
14	·69	1·51	60	·41	2·39	106	·60	·52
16	1·27	1·80	62	·26	1·70	108	·57	·59
18	1·83	2·16	64	·27	1·30	110	·44	·77
20	1·82	2·56	66	·36	1·13	112	·40	·83
22	1·76	2·50	68	·46	·95	114	·35	·72
24	1·60	2·26	70	·45	·95	116	·26	·62
26	1·52	2·13	72	·47	·78	118	·27	·40
28	1·07	1·59	74	·28	·80	120	·22	·28
30	0·78	1·04	76	·13	·48	122	·17	·21
32	1·52	·92	78	·19	·75	124	·19	·29
34	·50	·56	80	·29	·97	126	·31	·34
36	·46	·43	82	·48	1·23	128	·20	·48
38	·50	·41	84	·71	·93	130	·16	·48
40	·56	·62	86	·85	1·09	132	·14	·44
42	·77	·91	88	·98	1·06	134	·10	·28
44	·94	1·25	90	·87	1·15	136	·10	·16
46	·96	2·12	92	1·08	1·12	138	·23	·09
Means	0·86	1·18		0·60	1·56		0·41	0·50

4. We have to look for cases where the value of a^2+b^2 strikingly exceeds its mean value. The mean value should, however, be taken from the undisturbed portions of the periodogram, and there is always a little doubt in the first instance which these are. The means of the columns have been taken, and the mean of the six is 0·82. The highest value reached, 3·52, is only 4·4 times this mean; but if we exclude the column in which it occurs the mean falls to ·71, and the highest value, 3·52, is very nearly five times this. There is just a possibility that this peak indicates a real periodicity, though the probability is not high. It will be seen that there is a slight rise in the column for minima near the same value of A (viz. 52°), though the rise is far too slight to be worth notice independently. Still, there are obvious reasons why the minimum may be not so well determined as the maximum.

5. There is also a rise at A = 20°, though not quite so marked.

It is worth noticing, however, that the accompanying rise in the column for minima is greater, and that there are indications in some of the variable stars of another term accompanying the main inequality (see the case of S Serpentis in *M.N.*, lxviii. p. 563).

6. To state the case as favourably as possible for the existence of a periodic inequality in the sun-spot period, we may exclude from both columns the values

$$\text{from } A = 14^\circ \text{ to } A = 30^\circ, \text{ and from } A = 44^\circ \text{ to } A = 66^\circ,$$

and then the mean value for the periodogram for minima becomes 0·46 and for the maximum 0·62. The ratio of 3·52 to its own mean is thus nearly 6, and to the mean for both maximum and minimum is nearly 7.

7. Recurring now to the quantities which give us the inequality, if it exists, we find for the formulæ representing the maxima, when $A = 53^\circ$ (which seems the best value),

$$-1{\cdot}4 \sin 53^\circ E - 0{\cdot}2 \cos 53^\circ E,$$

and for the minima

$$-0{\cdot}7 \sin 53^\circ E - 0{\cdot}1 \cos 53^\circ E.$$

But the epochs are not quite the same. The minima begin with 1610·5, and the maxima with 1616·3, or 5·8 years later, which is $5{\cdot}8/11{\cdot}13 = {\cdot}52$ of a period. The phase of the inequality is thus advanced by $53^\circ \times {\cdot}52 = 27^\circ$ for the maxima, and to compare the expressions we must write

$$-1{\cdot}4 \sin (53^\circ E - 27^\circ) - 0{\cdot}2 \cos (53^\circ E - 27^\circ)$$

$$= -1{\cdot}3 \sin 53^\circ E + 0{\cdot}4 \cos 53^\circ E \quad \text{for maxima,}$$

and, as before,

$$-0{\cdot}7 \sin 53^\circ E - 0{\cdot}1 \cos 53^\circ E \quad \text{for the minima.}$$

8. In Chandler's notation, the sun-spot maxima would therefore be given by some such formula as

$$\text{const} + 4060 E + 490 \sin (53^\circ E + \text{const}),$$

and the question now arises how far this formula for the Sun accords with those found for the stars and quoted in § 1. Putting $P = 4060^d$ in these formulæ, we have

$$C = 7^d{\cdot}3 + 0^d{\cdot}064 \times 4060 = 267^d \text{ as against } 490$$

$$A = 2^\circ{\cdot}6 + 0^\circ{\cdot}018 \times 4060 = 76^\circ \text{ as against } 53^\circ.$$

There is, of course, no reason why these formulæ should be strictly linear, so far as we know at present; and if we remark that the value of the coefficient C obtained from the minima is only about half that obtained from the maxima (*i.e.* in sensible agreement with the star-formula), the accordance is sufficiently good

to suggest further inquiry. One fact emerges from the discussion, viz. that from the available material it is difficult to make sure of the existence of an inequality similar to those shown by the stars. We may take it that the coefficient C is of the right order of magnitude to fit in with the star-formula: and our periodogram shows that in this case it is too small to stand out clearly from the accidental inequalities. It will not be possible to affirm or deny the existence of such an inequality with confidence until the material is improved by extending the series of observations, or possibly by reducing the accidental errors of the older observations by improved discussions of them. One hope of reducing the accidental errors proved vain. It was thought that, since there are two independent series of maxima and minima, they might be used in combination in some way, so that the effect of accidental errors of one series might be reduced by the other. But apparently the two series run together so closely that not much can be gained in this way.

9. The value $A = 20^\circ$ gives a value of C not much smaller than that for $A = 53^\circ$; and from the material it is not easy to say which of these two possible terms corresponds to the terms found for variable stars. Are there possibly two terms in general? The case of S Serpentis has already been quoted, where the existence of a long-period term had masked the short-period term. In other cases there may be long-period terms affecting the short-period terms to a smaller extent, and this may account for some of the large deviations from the formula. And these two values $A = 53^\circ$ and $A = 20^\circ$ for the Sun may help us, by suggestion, in getting at the facts for the variables. The series of observed maxima for the Sun is much longer and more continuous than those for most of the variables; and it would not be surprising if we got suggestions from it which would help in elucidating the shorter series.

10. Assuming that the value $A = 53^\circ$ corresponds to the terms that have attracted attention for the variables, then the formula

$$A = 2^\circ{\cdot}6 + 0^\circ{\cdot}018 \times P$$

does not hold for so large a value of P as $P = 4060$; for which we should get $A = 75^\circ$, as remarked in § 7. Can this distant point on the curve be used to improve the formula?

11. Firstly, let us examine the consequence of assuming the formula still linear, and let us determine a and b in the expression

$$A = a + bP$$

so as to satisfy the Sun and the mean of the stars; that is, put

$$53^\circ = a + b \times 4060 \qquad \text{(the Sun)}$$

$$8^\circ{\cdot}16 = a + b \times 311 \qquad \text{(mean of stars)}.$$

From these we get $b = 0^\circ{\cdot}012$, $a = 4^\circ{\cdot}43$.

This new formula $A_2 = 4^\circ\cdot4 + 0^\circ\cdot012\ P$
differs from the former $A_1 = 2\cdot6 + 0\cdot018\ P$

as follows, for different values of P :—

	P =	100^d	200^d	300^d	400^d	500^d	600^d
New formula	A_2 =	5°·6	6°·8	8°·0	9°·2	10°·4	11°·6
Old formula	A_1 =	4·4	6·2	8·0	9·8	11·6	13·4
	$A_2 - A_1$ =	+1·2	+0·6	0·0	−0·6	−1·2	−1·8

It seems doubtful whether our present material is sufficient to enable us to discriminate between these two formulæ, for most of the stars have periods between 200 and 400 days. But we may notice one other supposition, viz.—

12. Secondly, let us adopt the suggestion of a curve of some kind rather than a straight line. The appropriate indices for A and P will be suggested by finding m in the formula

$$A^m = P$$

for the large values of A and P, *i.e.* for the case of the Sun. We have

$$m = \log P/\log A = \log 4060/\log 53$$
$$= 3\cdot61/1\cdot72 = 2\cdot1.$$

This suggests some formula such as either

$$A^2 = a(P + p)$$

or $$(A + \alpha)^2 = bP.$$

13. Determining the constants from the two cases of the Sun and mean of the stars, we find for the two suppositions

$$A^2 = 0\cdot73\ (P - 220)$$
$$(A + 9^\circ)^2 = 0\cdot94\ P$$

Of these, the former gives impossible values of A for periods below 220 days, and is thus unsuitable. The latter gives values of A for different values of P, as below.

P =	100^d	200^d	300^d	400^d	500^d	600^d	
A_3 =	0°·7	4°·7	7°·8	10°·4	12°·7	14°·8	(new formula).
A_1 =	5·6	6·8	8·0	9·2	10·4	11·6	(linear formula).
$A_3 - A_1$ =	−4·9	−2·1	−0·2	+1·2	+2·3	+3·2.	

These differences are larger than the former, and it seems probable that we can discriminate even now in favour of the original formula.

Summary.

The sun-spot maxima (and minima) occur on the average at intervals of 11·125 years. But the individual maxima (and minima) show discordances which have been tabulated for 26 periods by Wolfer. Analysing these by the periodogram method of Professor Schuster, there are indications of two periodicities, one of which the phase advances 53° per period of $11\frac{1}{8}$ years, the other of which the phase advances only 20°. The cycles are completed in about 75 and 200 years respectively. The amplitude of each inequality is about a year, but the accidental errors are so large that either or both of these inequalities may be spurious.

The quicker moving inequality (53°) can be brought into line with similar inequalities for the long-period variables; the best formula connecting A (advance of phase in degrees per period) with P (the period in days) being the simple linear formula

$$A = 4^\circ{\cdot}4 + 0^\circ{\cdot}012\ P.$$

The slower moving inequality (20°) may quite possibly have analogies in the stars, but as yet the material is not sufficient to declare.

Researches on the Solar Constant and the Temperature of the Sun. By Dr. J. Scheiner, Assoc. R.A.S.

In No. 55 of the Publications of the Astrophysical Observatory, Potsdam, I have published an extended paper on this subject, and I should like to give a short report of the results to the readers of the *Monthly Notices*.

The measures of the Sun's radiation were made with the Ångström Electric Compensation Pyrheliometer, to which I had given a modified exterior form and a parallactic motion with clockwork. On eleven days in June and July 1903 I made a long series of observations on the top of the Gorner Grat in Canton Wallis (Switzerland), from which I could derive the radiation of the Sun outside our atmosphere. This part of the problem is the most difficult one, and, according to my view, it cannot be solved from measurements of the solar radiation alone. From such observations a portion only of the real solar constant can be obtained, because only that portion of the loss by absorption in our atmosphere can be calculated which is based upon the *continuous* increase of absorption with growing thickness of the atmospheric layer traversed by the radiation. With carbon dioxide and water vapour there exists a nearly sudden absorption in the highest thin layers of the atmosphere, which must be treated as a constant to be added to the

result from the radiation-curves. Therefore this latter result is not the solar constant as generally supposed, and I have chosen for it the term "Strahlungsconstante" or "Constant of Radiation." From my observations on the Gorner Grat it amounts to 1·95–2·02 gr. cal. The remaining constant, which must be added to it for obtaining the Solar Constant, can be found only from experimental researches in the laboratory. To this part of the problem I have devoted much labour in measuring the absorption of carbon dioxide and superheated water vapour with varying depth of layer.

This very complicated research cannot be described in a short abstract, and I must therefore refer to the original paper. The result is that for reducing the Radiation Constant to the Solar Constant there must be added for carbon dioxide 1%, for water vapour 7%, and for the ultra violet absorption 1½%, whence the Solar Constant for the unit of distance is found to be 2·22–2·29 gr. cal., with a probable error of 2%.

The constant of the Stefan law, which is necessary for calculating the effective temperature of the Sun from the Solar Constant, I have ascertained by different methods, and with the same pyrheliometer, thus eliminating the constant error of the apparatus which cannot exceed 1 per cent. The "black radiation" of known temperature was measured from black platinum, rendered incandescent by an electric current, from light flames of different thicknesses, and from the artificial "black body." The latter results were the most exact and the effective temperature of the Sun based upon them was found to be 6196°–6252°.

Further on, I have endeavoured to calculate the real temperature of the solar photosphere from the effective temperature by employing the known data on the absorption of the solar atmosphere. Of course this research cannot be of the same exactness as the foregoing one, especially because the photosphere has no definite temperature, consisting as it does of layers of very different temperature.

Neglecting the errors arising from our ignorance of the structure of the photosphere, its average temperature comes out as 7065°.

The Total Solar Eclipse of 1910 *May* 8.

By A. M. W. Downing, D.Sc., F.R.S.

This eclipse is observable in Tasmania, though not under very favourable conditions, owing to the Sun's low altitude at the time of totality.

The particulars for Hobart are given on page 444 of the *Nautical Almanac* for 1910. It will be noticed that the Sun sets before the ending of the partial phase of the eclipse.

Port Davey, in the south-west of Tasmania, is, however, a more favourable station from which to observe the total phase of this eclipse, the duration of totality there being half a minute longer than the duration at Hobart. Some particulars of the eclipse as seen from Port Davey are given, as an example of eclipse calculations, on page 590 of the *Nautical Almanac* for 1910. For the convenience of observers these are reproduced here, and some additional particulars added.

Port Davey. Long. 146° 0′ *E. Lat.* 43° 22′ *S.*

Standard Mean Time (10^{h} *East*).

		d	h	m	s	Angle from North Point.	Vertex.
First contact	May	9	3	4	2	247°	99°
Total Eclipse		9	4	11	55	52	272
		9	4	15	25	267	127
Sun sets		9	5	8			

With the existing errors of the lunar tables, the predicted times for the phases of the eclipse given above will be several seconds too late. It may be useful, therefore, to add the intervals in time from the instant when the cusps subtend a given angle at the Sun's centre to the commencement of totality.

Angle of Cusps.	Time before commencement of totality.
°	s
90	42
60	16
45	9
30	4
15	1

The Sun's altitude at the time of totality is 8°.

The Perturbations of Halley's Comet in the Past. Fifth Paper. The period B.C. 240 *to* A.D. 760. By P. H. Cowell and A. C. D. Crommelin.

We have once more to commence by acknowledgment of the continued assistance that we have received from Dr. Smart and Mr. Cripps in the calculation of the mechanical quadratures.

The fourth paper of this series (*M.N.*, May 1908) traced the comet back to A.D. 760 June 10 (Julian day 1998810), the corrected value of n at that epoch being $46''\cdot113$. Hind's date for the previous passage is 684 Oct. 18, though the observed positions are too vague to fix the time of perihelion within several days. Mr. Knobel has shown that this comet was also observed in Japan (*M.N.*, lxvi., 2, p. 72) the date of first apparition, 684 Sept. 7, being in good accord with the date Sept. 6 of the Chinese records; he has, however, by a slip, given Hind's date of perihelion passage as Sept. 18 instead of Oct. 18.

Our computations indicate that Hind's identification is correct, the calculated date being 39 days later than his, which is a reasonable discordance for that remote epoch.

Revolution 684–760.

Planet.	Limits of u.	$\int dn$.	$\int d\varpi$.	$\int d\zeta$.
Venus	0°–30°	$-''\cdot002$	...	$-''\ 56$
,,	330–360	$-\cdot006$	...	...
Earth	0–30	$+\cdot011$	...	+ 308
,,	330–360	$-\cdot002$	...	...
Jupiter	0–90	$+1\cdot137$	+560	+31720
,,	90–270	$+\cdot148$	−523	+ 636
,,	270–360	$-\cdot983$	+ 48	+ 170
Saturn	0–90	$+\cdot0219$	+ 34	+ 612
,,	90–270	$-\cdot0312$	−129	− 466
,,	270–360	$+\cdot0381$	+ 54	− 7
Uranus	0–360	$+\cdot012$	...	+ 280
	Sums	$+\cdot344$	+ 44	+33197

Taking n in 760 as $46''\cdot113$, n in $684 = 45''\cdot769$, and period in days $= \frac{1296000 - 33197}{45\cdot769} = 27591$, which brings us to J.D. 1971219 $= 684$ Nov. 26.

The observations will scarcely permit so late a day as this for the perihelion passage. If we take the mean of Hind's value (Oct. 18) and our value Nov. 26 as the actual date, we must take n in 684 as $45''\cdot737$.

Proceeding to the revolution before this, an approximate computation quickly showed that Hind's date 608 Oct. 19 was about $1\frac{1}{2}$ year too late. Dr. Ångström had already deduced from his empirical curve that "l'apparition pour l'année 608, présentant l'écart le plus grand, est probablement douteuse." Every alteration to Hind's dates that we have found brings the results into closer accord with Ångström's curve, a fact which renders its failure for the next return more surprising. We propose examining this question further in a subsequent paper.

The observations of 607 are in a decided tangle; it seems clear that they refer to, at least, two different comets (some say that no less than four appeared in this year). Halley's comet seems to have appeared in the spring, and the date March 20 was selected for the purpose of computing the perturbations.

Revolution 607–684.

Planet.	Limits of u.	$\int dn$.	$\int d\varpi$.	$\int d\zeta$.
Venus	0°–30°	+″·001	...	+″28
,,	330–360	−·005	...	...
Earth	0–30	−·007	...	−196
,,	330–360	+·003	...	...
Jupiter	0–90	−·189	−452	−5954
,,	90–270	−·126	...	+4877
,,	270–360	+·491	−157	−122
Saturn	0–90	−·051	−37	−1438
,,	90–270	+·062	...	+2044
,,	270–360	−·185	...	+30
Uranus	0–360	+·006	...	+80
	Sums	−·000	...	−651

Taking n in 684 as 45″·737, n in 607 = 45″·737, and period in days $= \frac{1296000 + 651}{45{\cdot}737} = 28350$ days. Subtracting this from 1971199 (the adopted Julian day in 684) we obtain J.D. 1942849 = 607 March 26.

At this point we have somewhat varied the former procedure; owing to the difficulty of deciding from observation the exact day of perihelion in 607, we took the well-established return of 451 July 3·5 = J.D. 1885969·5 as a starting-point and assumed in a preliminary computation that the subsequent passage occurred in 530 November, in accordance with Hind. The verification of the date 530 November makes the revolution 451–530 the longest on record; it is about three months longer than 1066–1145 or 1222–1301,

which are very nearly equal in length. The adopted date is 530 November 15 = J.D. 1914959.

On this basis the perturbations were carried forward to 607, and it was found that nearly the same date was arrived at as in the previous backward reckoning. The value obtained for n in 607 differs somewhat, but this is easily accounted for when we note that in the three consecutive returns of 530, 607, 684 the observations are so vague that there is an uncertainty of a fortnight or so in the date of perihelion in each case. It is sufficient to know that our comet is correctly identified in each year, and we must be content with this small uncertainty in the dates.

Perturbations for the two revolutions 451–530, 530–607.

		Revolution 451–530.			Revolution 530–607.		
Planet.	Limits of u.	$\int dn$.	$\int d\varpi$.	$\int d\zeta$.	$\int dn$.	$\int d\varpi$.	$\int d\zeta$.
Venus	0°– 30°	+″·018	...	+″ 504	+″·020	...	+″ 560
,,	330–360	−·013	...	...	−·007	...	...
Earth	0– 30	+·003	...	+ 84	+·014	...	+ 392
,,	330–360	+·003	...	...	−·011	...	...
Jupiter	0– 90	−·2455	−213	−7179	+1·106	+633	+30974
,,	90–270	−·0134	−189	+7852	+·222	−348	+ 1969
,,	270–360	+·6501	−240	− 164	−·734	−295	+ 193
Saturn	0– 90	−·0077	+ 56	− 223	+·196	− 18	+ 5498
,,	90–270	+·0248	−101	+ 49	−·073	− 10	− 237
,,	270–360	−·0047	+ 4	+ 10	+·056	− 20	− 10
Uranus	0–360	−·001	...	+ 17	+·002	...	− 15
	Sums	+·425	−683	+ 950	+·791	− 58	+39324

For the revolution 451–530 we have the equation $\frac{1296000 - 950}{n \text{ at } 451} = 28990$, the observed period in days. Hence n at 451 = 44″·672, n at 530 = 45″·097.

For the revolution 530–607 we have the equation $\frac{1296000 - 39324}{45{\cdot}097}$ = period in days = 27866. Adding this to J.D. 1914959 we obtain J.D. 1942825 = 607 March 2, and n in 607 = 45″·097 + ″·791 = 45″·888. As the actual date of perihelion in 607 was probably at the end of March, we should have to diminish n in 530, 607 by about 0″·05, which would make a difference of only 0″·09 between the value of n in 607 found by forward reckoning, and that already reached by backward reckoning.

In carrying the research still further back, we have changed our method at this point, and used only the approximate tables given on p. 458 of the present volume, combined with the definite integral table on p. 178. This method is less accurate than that hitherto followed, and we must be prepared for errors of two or

three months in the computed periodic time, corresponding to $0''.15$ or $0''.20$ in the value of n; but this is near enough to test the accuracy of Hind's dates, which may be taken as presumably right if they fall within two months or so of the time indicated by our method; and, as a matter of fact, the results establish the accuracy of all Hind's dates from A.D. 451 back to B.C. 12, which is a very satisfactory conclusion. In his whole series there were only four errors, viz. A.D. 1223 (eleven months too late), A.D. 912 (four months too early), A.D. 837 (one month too late), A.D. 608 (one and a half years too late).

The research has been carried beyond the limits of Hind's list, and one fairly certain return has been added, that of B.C. 87. The description in Williams is, "In the second year of the epoch How Yuen (*i.e.* B.C. 87), the seventh moon (August), there was a comet in the east." Perihelion would be B.C. 87 August or September. Calculation indicates B.C. 163 June for the preceding passage, but no definite observation can be found in this year; Pingré has several vague references to comets about this epoch, but they are so wanting in precision that no use can be made of them. Going back another round, the date B.C. 239 January was found; we think it not unlikely that the comet observed in the spring of B.C. 240 was Halley's.

The discordance from our date is not greater than we might reasonably expect when the approximate method is used without check for two revolutions, and the characteristics of the comet of B.C. 240 are very like those exhibited by Halley's comet when perihelion falls about April.

Williams says, "In the seventh year of the reign of Che Hwang (B.C. 240) a comet first appeared in the east. It was afterwards seen in the north. In the fifth moon (May) it was seen for 16 days in the west."

For the two preceding passages there are no comets in either Pingré or Williams that could possibly be Halley's. Three revolutions earlier, there is the following in Williams: "In the second year of the Emperor Ching Ting Wang (B.C. 467) a comet was seen." This is at about the time when we should expect Halley's comet, but the identity cannot become more than a vague conjecture.

To sum up, we have carried the comet with fair certainty back to B.C. 87, with some probability back to B.C. 240; at this point we are brought to a standstill by the complete absence of earlier observational material.

The perturbations for the different rounds are given in the following tables. In each revolution $\frac{1296000 - \int d\zeta}{n \text{ at beginning of rev.}} =$ period in days; an equation which gives n when the period is assumed, or which gives the period when the value of n at the end of the period is assumed, and the value at the beginning deduced by applying the calculated perturbation of n.

Dates of beg. and end of Rev.				373 November 7; 451 July 3			295 April 7; 373 November 7			218 April 6; 373 April 7		
Values of g' for $u=$ 0°, 90°, 270°, 360°	Jupiter			352°, 218°, 322°, 189°			126°, 355°, 123°, 352°			309°, 173°, 262°, 126°		
	Saturn			247, 338, 25, 116			7, 99, 155, 247			146, 236, 277, 7		
				$\int dn.$	$\int d\varpi.$	$\int d\zeta.$	$\int dn.$	$\int d\varpi.$	$\int d\zeta.$	$\int dn.$	$\int d\varpi.$	$\int d\zeta.$
Jupiter	0°	–	90°	+″·770	−290″	+21972″	−″·120	+258″	−3539″	+″·330	−583″	+9369″
,,	90	–	270	− ·074	−242	− 3697	+·103	−162	+7862	− ·249	−163	−2282
,,	270	–	360	−1·040	+190	+ 168	+·210	−500	− 45	−1·270	+700	− 6
Saturn	0	–	90	− ·02	− 77	− 567	+·150	− 20	+4330	− ·036	+ 55	−1018
,,	90	–	270	+ ·037	+ 50	+ 2142	−·059	− 31	− 280	+ ·047	−110	+ 608
,,	270	–	360	− ·110	− 66	+ 20	+·060	+ 17	− 10	− ·050	+ 3	+ 10
			Sums	− ·437	−435	+20035	+·344	−438	+8318	−1·228	− 98	+6681

Dates of beg. and end of Rev.				141 March 25, 218 April 6			66 January 26, 141 March 25			B.C. 12 Oct. 8, A.D. 66 Jan. 26			B.C. 87 Aug. 15, B.C. 12 Oct. 8		
Values of g' for $u=$ 0°, 90°, 270°, 360°	Jupiter			132°, 355°, 85°, 309°			12°, 231°, 274°, 132°			217°, 79°, 150°, 12°			95°, 314°, 358°, 217°		
	Saturn			285, 15, 56, 146			86, 174, 197, 285			234, 324, 357, 86			36, 124, 146, 234		
				$\int dn.$	$\int d\varpi.$	$\int d\zeta.$	$\int dn.$	$\int d\varpi.$	$\int d\zeta.$	$\int dn.$	$\int d\varpi.$	$\int d\zeta.$	$\int dn.$	$\int d\varpi.$	$\int d\zeta.$
Jupiter	0°	–	90°	−″·190	+200″	−5459″	+″·940	−114″	+25968″	−″·217	−373″	−6128″	+″·848	+640″	+23305″
,,	90	–	270	+·244	− 68	+7788	− ·224	−464	− 3417	−·018	+246	+6584	+·269	−492	+ 3568
,,	270	–	360	−·047	−600	+ 43	−1·280	+710	+ 23	+·328	−447	− 94	−·853	− 97	+ 197
Saturn	0	–	90	+·055	− 95	+1578	+ ·010	+ 16	+ 285	−·036	− 58	−1003	+·058	− 54	+ 1606
,,	90	–	270	−·005	+ 78	+1630	− ·034	−129	− 462	+·063	+ 33	+2142	−·075	− 64	− 596
,,	270	–	360	−·038	− 86	+ 4	+ ·035	+ 50	− 10	−·192	− 22	+ 30	+·060	0	− 10
			Sums	+·019	−571	+5584	− ·573	+ 69	+22387	−·072	−621	+1531	+·307	− 67	+28070

Dates of beg. and end. of Rev.				B.C. 163 May 20; B.C. 87 Aug. 15			B.C. 240 May 15; B.C. 163 May 20		
Values of g' for $u =$ 0°, 90°, 270°, 360°			Jupiter / Saturn	302°, 163°, 233°, 95° / 185, 274, 307, 36			125°, 349°, 78°, 302° / 323, 53, 94, 184		
				$\int dn.$	$\int d\varpi.$	$\int d\zeta.$	$\int dn.$	$\int d\varpi.$	$\int d\zeta.$
Jupiter	0°	–	90°	+″·260	−″·607	+″7321	−″·090	+″280	−″2596
,,	90	–	270	−·307	− 63	−1561	+·254	− 89	+ 7326
,,	270	–	360	+·054	+ 15	− 120	−·093	−600	+ 62
Saturn	0	–	90	−·060	+ 15	−1691	+·163	− 73	+ 4569
,,	90	–	270	+·074	− 66	+1484	−·049	+ 52	+ 704
,,	270	–	360	−·174	+ 16	+ 22	+·018	− 76	− 24
			Sums	−·153	−690	+5455	+.203	−506	+10041

The date B.C. 240 May 15 was deduced from observation, not from calculation. The date calculated is B.C. 239 Jan. If we suppose an error of two months in the same direction in each of the calculations of the last two revolutions (which is quite probable), the discordance would almost disappear. It appears worth while to calculate the three revolutions B.C. 12 to B.C. 240 by more exact methods, and we hope to undertake this at a later date.

The following table gives the values of n calculated from the above results for the different revolutions, and also smoothed values resulting from the combination of values from consecutive revolutions.

Perihelion Passage.		n.	Smoothed n.	Perihelion Passage.		n.	Smoothed n.
		″	″			″	″
			45·742				45·862
A.D.	684	45·737		A.D.	218	45·88	
	607	45·747			141	45·86	
			45·818				45·835
	607	45·888			141	45·817	
	530	45·097			66	46·39	
			45·085				46·397
	530	45·097		A.D.	66	46·398	
	451	44·672		B.C.	12	46·47	
			44·604				46·483
	451	44·54			12	46·497	
	373	44·98			87	46·19	
			45·095				46·185
	373	45·19			87	46·185	
	295	44·845		B.C.	163	46·34	
			44·715				
	295	44·617					
A.D.	218	45·845					

Diagram showing the positions of Jupiter's Satellites VI, VII, and VIII, from photographs taken at the

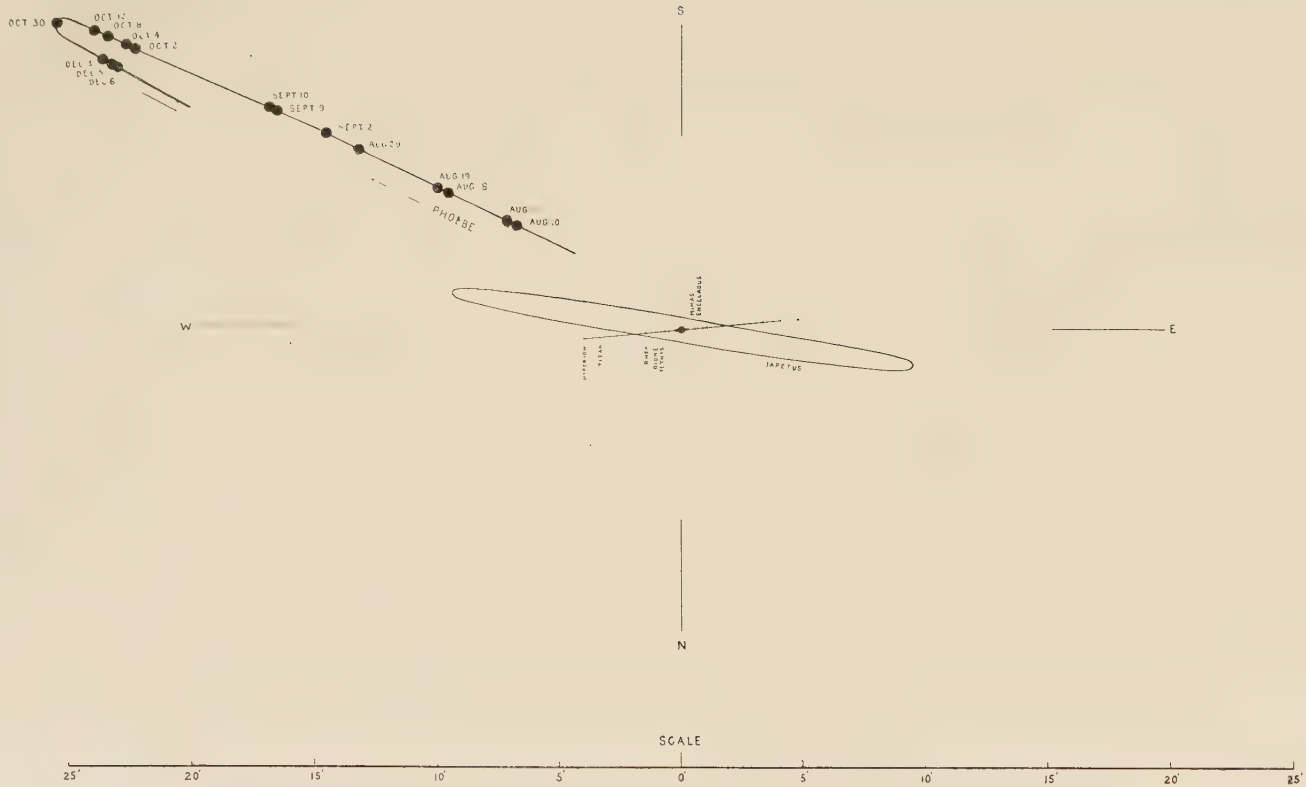


Diagram showing the position of Saturn's Ninth Satellite—Phœbe, from photographs taken at the Royal Observatory, Greenwich, during the Opposition of 1907.

Diagram showing the positions of Jupiter's Satellites VI, VII, and VIII, from photographs taken at the Royal Observatory, Greenwich, during the opposition of 1907–8. (Plate 15.)

(*Communicated by the Astronomer Royal.*)

The diagram is a graphical representation of the observations of Jupiter's Satellites VI, VII, and VIII, from photographs taken at the Royal Observatory, Greenwich, with the 30-inch reflector during the opposition of 1907–8, printed in the *Monthly Notices*, vol. lxviii. p. 582. In all, 38 photographs of Satellite VI, 21 of Satellite VII, and 13 of Satellite VIII have been obtained.

The positions plotted in the diagram are the means when two or more photographs were taken on any night, and the curves are drawn through these points.

For comparison, the orbits of the four inner large satellites are shown, the major axes being plotted to scale, but the minor axes intentionally exaggerated.

The apparent convexity of the path of the eighth Satellite with regard to Jupiter is due to the Earth's motion during the period over which the observations extend (about three months), and the consequent change in the point of view.

Royal Observatory, Greenwich:
1908 *September* 23.

Diagram showing the positions of Saturn's Ninth Satellite—Phœbe, from photographs taken at the Royal Observatory, Greenwich, during the opposition of 1907. (Plate 16.)

(*Communicated by the Astronomer Royal.*

This diagram is a graphical representation of the observations of Saturn's ninth Satellite—Phœbe—from 16 photographs taken at the Royal Observatory, Greenwich, with the 30-inch reflector during the opposition of 1907, printed in the *Monthly Notices*, vol. lxviii. p. 211.

The observed position of Phœbe with respect to Saturn on each day of observation is plotted in the diagram, and the curve drawn through these points.

For comparison, the orbits of the inner satellites are shown plotted to scale.

It may here be noted that during the present opposition (1908) 23 photographs on 15 nights have already been obtained up to the present time, the first being on July 31, some few days before Phœbe reached eastern elongation.

Royal Observatory, Greenwich:
1908 *September* 23.

The Relation between Star Colours and Spectra.

By W. S. Franks.

In a former paper on this subject (*Monthly Notices*, June 1907) I gave the result of an investigation into the relation between the colours and spectra of 1360 bright stars, in both hemispheres; the colours depending on the observations made by members of the British Astronomical Association in England and Australia. The stars observed in this country, from the N. pole to 25° south declination, amounted to 928 of the total number. The recent publication of the *Revised Harvard Photometry*, which contains over 9000 stars down to 6½ magnitude, has enabled me to carry this inquiry a stage further. Making use only of my own colour observations, contained in a MS. synoptic catalogue of 4175 stars (which includes *all* my previous work in this direction), I have carefully compared this with the Harvard revised spectra. The number of stars between the N. pole and −25°, common to both lists, amounts to 3497; which is nearly four times greater than the B.A.A. total, and it includes stars down to 6½ magnitude. As the colour estimates in my earlier catalogues were not expressed by symbols, like the B.A.A. and my later observations, I have used the old notation in this paper—dividing the colours into seven groups, as here shown :—

		Symbol.
1. White	Stars—including bluish-white and greenish-white . .	O
2. Yellowish White	,, —an important and well-marked class . . .	Y^1
3. Pale Yellow	,, —including a few pale orange-yellow . . .	Y^2
4. Yellow	,, —(normal tint) including orange yellow and full yellow	Y^3
5. Pale Orange	,, —a distinctive group	Or^2
6. Orange	,, —(normal tint) including also full orange . .	Or^3
7. Orange Red	,, —including all ruddy tints	OrR^2

The foregoing colours are distributed as follows :—

Colour.	Number.	Percentage.
1. White	1083	31·0
2. Yellowish White	729	20·8
3. Pale Yellow	782	22·4
4. Yellow	413	11·8
5. Pale Orange	271	7·7
6. Orange	195	5·6
7. Orange Red	24	0·7
Total	3497	100·0

Analysis of Colours and Spectra.

Table I.

Colour.	*Spectrum Types.*																
	Od	Oe	Oe5B	B	B1A	B2A	B3A	B4A	B5A	B8A	B9A	A	A2F	A3F	A4F	A5F	A8F
White	...	...	5	23	9	22	88	...	49	69	21	605	79	18	1	28	2
elsh. Wh.	...	...	4	3	8	10	11	1	17	13	10	254	41	20	...	63	2
ale Yell.	1	1	1	...	...	...	1	...	...	3	2	38	12	4	...	13	1
Yellow	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
le Orange	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	..	...
Orange	...	...	...	...	...	...	...	...	...	...	...	..	...	...	...	...	...
range Red	...	...	...	...	...	...	...	...	...	...	...	...	...	..	...	...	...
Total	1	1	10	26	17	32	100	1	66	85	33	897	132	42	1	104	5

(continued below.)

Colour.	*Spectrum Types.*																
	F	F2G	F5G	F7G	F8G	G	G2K	G5K	G8K	K	K2M	K5M	Ma	Mb	Mc	Md	N	Total.
White	44	4	7	...	2	7	...	...	...	...	...	...	...	...	...	...	...	1083
lsh. Wh.	134	5	47	1	18	37	3	10	...	17	...	...	...	...	...	...	...	729
ale Yell.	110	19	51	1	36	102	15	88	...	260	2	10	8	3	...	...	...	782
Yellow	8	1	4	...	6	22	4	35	1	274	7	25	20	6	...	...	...	413
le Orange	...	...	2	...	1	13	3	24	...	155	2	27	30	14	...	...	...	271
Orange	...	...	...	...	...	2	2	9	...	84	3	33	45	12	1	1	3	195
range Red	...	...	...	...	...	...	...	2	...	4	...	...	6	1	...	3	8	24
Total	296	29	111	2	63	183	27	168	1	794	14	95	109	36	1	4	11	3497

Summary of Analysis.

Table II.

Group.	Spectrum Type.	White.	Yelsh. Wh.	Pale Yel.	Yellow.	Pale Or.	Orange.	Orange Red.	Total.
Od and Oe	Bright line spectra	...	...	2	...	...	...	...	2
Oe5B	Intermediate	5	4	1	...	...	...	...	10
B to B5A	Orion type	191	50	1	...	...	...	...	242
B8A ,, A4F	Sirius ,,	793	338	59	...	...	...	...	1190
A5F ,, F2G	α Carinæ ,,	78	204	143	9	...	...	...	434
F5G	Procyon ,,	7	47	51	4	2	...	...	111
F7G to G8K	Capella ,,	9	69	242	68	41	13	2	444
K	Arcturus ,,	...	17	260	274	155	84	4	794
K2M and K5M	Aldebaran ,,	...	...	12	32	29	36	...	109
Ma to Md	Betelgeuse ,,	...	...	11	26	44	59	10	150
N	19 Piscium ,,	...	...	...	...	...	3	8	11
	Total	1083	729	782	413	271	195	24	3497

Percentage of Colours in each Group.

TABLE III.

Group.	White.	Yelsh. Wh.	Pale Yel.	Yellow.	Pale Or.	Orange.	Orange Red.	Total.
Od and Oe	...	...	100·0	...	...	...	...	100·0
Oe5B	50·0	40·0	10·0	...	...	...	..	100·0
B to B5A	78·9	20·7	0·4	...	...	...	...	100·0
B8A ,, A4F	66·6	28·4	5·0	...	...	...	...	100·0
A5F ,, F2G	18·0	47·0	33·0	2·0	...	...	...	100·0
F5G	6·3	42·3	46·0	3·6	1·8	...	...	100·0
F7G to G8K	2·0	15·5	54·5	15·3	9·2	3·0	0·5	100·0
K	...	2·1	32·8	34·5	19·5	10·6	0·5	100·0
K2M and K5M	...	...	11·0	29·4	26·6	33·0	...	100·0
Ma to Md	...	...	7·3	17·3	29·3	39·4	6·7	100·0
N	...	...	...	...	...	27·3	72·7	100·0

Classification of Spectra in Tables II. and III.

Photo. Spectra.				Visual Spectra
Oa to Oe	—Bright line spectra	. . .	=	V.
Oe5B	—All dark lines (intermediate between O and B)		=	V–I.
B to B5A	—Helium ,, Orion type	B . .	=	I*a*.
B8A to A3F	—Hydrogen ,, Sirius ,,	A . .	=	I*b*.
A5F to F2G	— do. ½ intensity *a* Carinæ ,,	F . .	=	I–II*a*.
F5G	— (Intermediate) Procyon ,,	F5G . .	=	I–II*b*.
F8G to G5K	— Solar lines Capella ,,	G . .	=	II.
K	— "K" line intense Arcturus ,,	K . .	=	II–III*a*.
K2M and K5M	— (Intermediate) Aldebaran ,,	K5M . .	=	II–III*b*.
Ma to Md	— Banded spectra Betelgeuse ,,	Ma . .	=	III.
N	— do. (reversed) 19 Piscium ,,	N (ruddy stars)	=	IV.

The last class (N) would be considerably increased but for the difficulty of photographing objects near the red end of spectrum—hence they fall short of the number that can be observed visually. A number of red and orange stars of $6\frac{1}{2}$ magnitude, contained in my catalogue, are, from this cause, entirely omitted from the Harvard spectra results.

Deductions from preceding Tables.

ectrum O—	*Maximum*	in white, gradually decreasing to pale yellow.
,, B—	,,	,, ,, (practically 79 per cent.). The *whitest* stars.
,, A—	,,	also ,, but less wh. and more yelsh. wh. than B.
,, F—	,,	,, yelsh. white, but the pale yellow not far behind.
,, F5G—	,,	between yelsh. wh. and pale yel.—the latter slightly in excess.
,, G—	,,	in pale yellow—very pronounced.
,, K—	,,	between pale yel. and yellow—nearly equal.
.. K2M and K5M	,,	pretty evenly distributed between yel., pale or., and orange.
,, M—	,,	in orange, but pale orange not far behind.
,, N—	,,	orange red—very pronounced.

The *sequence* of *colours* corresponding to the *sequence* of the *spectra* is thus unmistakably indicated. But in the A class there is a definite number of pale yellow stars; their occurrence is too frequent and regular to be accidental; they show an increase in frequency in the regions where coloured stars are predominant. Likewise there is a still larger fraction of white stars in the F class—contrary to the normal. This serves to emphasise the fact that in some cases two stars of exactly the same colour visually are of different spectral types—some noteworthy examples of which have come to light during the present investigation. And, conversely, some stars of identical spectra differ very perceptibly in colour—whatever the cause of such discrepancy may be. But perhaps these exceptions, which after all are not very numerous, merely point the rule which governs the relation between colour and spectrum in the great majority of cases. If I have succeeded in establishing this connection, it may be also a plea that star colour observations *do* possess some value; and I shall consider that these thousands of independent estimates, which have so long lain dormant, were not altogether made in vain.

Uxbridge: 1908 *August* 12.

Note on Y Cephei. By Rev. J. G. Hagen, S.J.

(*Communicated in a letter to the Astronomer Royal.*)

"The advance prints of your Astrographic Plates 3619 and 6983, which you kindly sent me for the examination of Y Cephei and its surroundings, have enabled me to measure the additional stars to the Atlas Chart of this variable which were invisible in the 12-inch refractor. They will be recorded in the Catalogue sheet No. 188 of series vi., with due acknowledgment.

"Since the magnitudes of this series are all reduced to the Harvard scale, it is well to put the magnitudes of Y Cephei, as shown on your plates, on record for future corrections of the elements of variation. The following extract from the Catalogue will designate four comparison stars :—

No. 3.	$\Delta\alpha = -0^m\,20^s$	$\Delta\delta = -11'{\cdot}5$	H.P. $8^m{\cdot}7$	letter c
4.	,, $+3^m\,20^s$	,, $-12'{\cdot}1$	,, $8^m{\cdot}8$	,, d
37.	,, $0^m\,0^s$	,, $-1'{\cdot}5$	,, $12^m{\cdot}7$	,, ϕ
40.	,, $+0^m\,30^s$	,, $-1'{\cdot}0$	,, $13^m{\cdot}1$	,, τ

Your plates give the following estimates, which anyone can verify :—

Pl. 3619,	1897 Sept. 9 :	c2Y4d,	Magn. 8·7 H.P.
,, 6983,	1908 Jan. 12 :	ϕ4Y1τ,	,, 13·0 ,,

"The provisional elements of variation give the following corresponding epochs of maxima :—

Max. 1897 Sept. 24 = Plate 3619 + 15 days.

,, 1907 Nov. 26 = ,, 6983 − 47 days.

"The first plate agrees well with the computed maximum and with the remark of Ceraski (*A.N.* 3644) that the brightness of Y was diminishing in October 1897. The second plate, however, will probably demand a correction to the assumed elements (*A.N.* 3744 and *V.J.S.* 41, page 317), as it is unlikely that the star should have diminished in brightness by $4\frac{1}{2}$ magnitudes in 47 days."

Rome : July 22, 1908.

Corrections to Professor Turner's paper on Correlation,—
(M.N., p. 551).

An unfortunate slip on p. 551 has been kindly pointed out by Mr. J. B. Dale.

Both σ_A and σ_B should have been divided by 3, the square root of the number of observations; so that

$$\sigma_A = 1{\cdot}15 \qquad \sigma_B = 0{\cdot}82$$

and

$$r = {\cdot}72 \text{ } \textit{instead of} \text{ } {\cdot}08.$$

The correlation between A and B is therefore by no means negligible as stated on p. 552, and again on p. 545.

The two "regression lines" are

$$(A-7) = r.\frac{\sigma_A}{\sigma_B}(B-7) \quad \text{and} \quad (B-7) = r.\frac{\sigma_B}{\sigma_A}(A-7)$$

or

$$(A-7) = 2(B-7) \quad \text{and} \quad (B-7) = (A-7)$$

which are the two solutions mentioned on p. 545 obtained by grouping according to B and to A respectively.

The example was subsidiary, and the slip does not affect the main argument; but it is not easy to understand how so gross an error passed undetected. H. H. T.

Errata in Mr. J. M. Baldwin's paper on Neptune.

p. 618, line 26, *for* include *read* exclude.

p. 620, line 4, *for* showing in *read* showing an.

LIST OF ADDITIONS

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An asterisk (*) indicates that the work is an excerpt.

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